CHAPARRAL CONVERSION POTENTIAL IN ARIZONA

Part I: Water Yield Response and Effects on Other Resources

by Alden R. Hibbert, Edwin A. Davis, and David G. Scholl

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Abstract

On areas favorable for treatment, conversion to grass reduces fire hazard and substantially increases water yield and forage for livestock. If treatment areas are kept small and interspersed with native chaparral, protective cover and browse for game animals will always be available nearby, and the edge effect created by the openings will enhance the overall environment for wildlife. Chaparral control methods that have proved effective in Arizona are rootplowing, prescribed burning, chemicals, and chemicals in combination with the others. Stream water from treated watersheds shows moderate to low contamination by herbicides. Over the long run, conversion should reduce erosion by reducing or eliminating the heavy erosion cycle set off by periodic wildfires in unmanaged chaparral.

Keywords: Watershed management, chaparral, brush control, water yield improvement, soil erosion, sediment yield, habitat improvement.

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[Water supply]

2501 by
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Contents

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Part I: Water Yield Response and Effects on Other Resources

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INTRODUCTION

In the wake of concern over a dwindling water supply in central Arizona, conversion of chaparral to grass has been advocated by some as a means to augment streamflow. Early research efforts by the USDA Forest Service aimed primarily at grazing and erosion problems were expanded in the 1950's to study the feasibility of increasing water yield in this manner. Effects of conversion on other resources were also evaluated. Part I of this publication reports research activities to increase water yield, and the effects of treatment on erosion, wildlife, and forage production. Part II, a separate paper by Brown et al. (1974), further evaluates the impact of conversion on fire hazard, recreation, and esthetics, and utilizes these findings in an economic analysis of converting chaparral on National Forest land in the Salt-Verde Basin, Arizona.

Experimental conversions on small brush-covered watersheds have substantially increased water yield and forage production for livestock and game animals. Control of wildfire is eased by breaking up large, continuous expanses of heavy brush. Conversion changes the wildlife habitat, favorably for some species, unfavorably for others. Although conversion activities may temporarily increase erosion, the long-term rate should decrease if further soil disturbance is minimized. Burning and chemical control of brush usually leave an esthetically unpleasant appearance for several years until shrub skeletons deteriorate and replacement cover is well established. Proper blending of treated with untreated areas increases the edge effect and creates a mosaic or savanna appearance that can be both esthetically pleasing and productive of game and wildlife.

Research and management must develop sound, efficient, and safe prescriptions for converting chaparral. Much research has been done in shrub control and water yield determinations. More work is needed on methods of establishing and maintaining replacement cover, predicting response to treatment, and safeguarding against long-term degradation of the environment.

RESEARCH BACKGROUND

Chaparral received early attention in California, where shrub species are similar but management problems are more acute than in Arizona. By the late 1800's it was apparent to some that burning or clearing brush in the San Gabriel Valley increased flows and accelerated flood damage (Robinson 1946). The effect of wildfire on streamflow was first documented by Hoyt and Troxell in 1934. They found that wildfire caused the average annual flow on Fish Creek near Monrovia to increase 29 percent or 1.55 inches. While the erosion caused by the increased flows after the fire did not particularly disrupt onsite watershed resources, the deposition of eroded material downstream on agricultural lands and transportation rights-of-way was materially damaging. They concluded that the water user and land manager must weigh the benefits of the extra water against the cost of damages downstream to determine management alternatives for brush lands in water-short areas.

These findings only intensified the controversy surrounding brush burning in California. Livestock interests had long advocated controlled burning to enhance forage production and restrict further expansion of brush into grasslands. Now they were being supported by water interests, at least as long as the water remained "usable" and did not come as destructive floods and mud flows. The extent of the controversy and the general state of knowledge were well summarized in a 1947 report by Adams, Ewing, and Huberty.

As more research was done on the plant-soil-water relations in the chaparral and woodland types (Veihmeyer 1953, Burgy 1958, Rowe and Reimann 1961, Merriam 1961, Lewis 1968), two important facts became clear. First, streamflow and seepage to ground water increase when these cover types are converted to grass. Second, the loss of soil stability caused by conversion — whether by burning or other means — presents the immediate threat of floods and debris flows, particularly on the steep, unstable slopes of southern California brushlands.

In Arizona, research aimed specifically at improving water yield did not begin until the 1950's. Earlier studies by the USDA Forest Service were focused on plant-soil-water relations and on the influence of grazing on runoff and erosion. Range improvement studies were started in various locations in the Salt River drainage in 1921. The Summit plots near Globe were established in 1925 (Rich 1961), and in 1932, the Sierra Ancha Experimental Forest near Roosevelt Lake was set aside for watershed research (USDA Forest Service 1953; Pase and Johnson 1968).

These early research efforts established many of the basic concepts and the functional relationships between climate, plants, soils, and land use which are now taken for granted. Much of the basic hydrology of the Salt River watershed was described by Cooperrider and Sykes in 1938. While some revision and modification has been necessary in the face of recent findings, the bulk of their report is as valid today as it was in the 1930's. In summarizing their report, Cooperrider and Sykes stressed that, although water yield might conceivably be increased by changing the vegetation, it was as yet unproved as a practical means of improving water supply. Their greatest concern was the ultimate deterioration of the soils resulting from overgrazing, fire, or other methods of reducing the cover. Although flooding and debris flows were less severe than in southern California, they feared that treatment would increase surface runoff and erosion, and that reservoirs would fill with sediment to intolerable levels. This concern is less valid today. We have found that water yield can be improved without unduly accelerating erosion if care is taken in the conversion process. However, there is little cause for complacency; the erosion rate must be further reduced if the effectiveness of storage systems is to be preserved.

Concern over the water situation intensified as runoff from central Arizona watersheds continued to decline through the 1940's and 1950's. While some attribute the decline to an increase in brush and trees following decades of overgrazing and fire protection (Wingfield 1955, Warskow et al. 1969), others cite a concurrent decline in precipitation as the major cause (Barr 1956, McDonald 1960). In any event the demand for water has long exceeded the surface supply, and about 4 million acre-ft is being "mined" each year from ground water. Of the estimated 80 million acre-ft of rain and snow received each year by Arizona, only about 2 million acre-ft or 2½ percent is yielded as streamflow (Harshbarger et al. 1966). Since transpiration by vegetation, much of it considered to be nonbeneficial, requires so much water, ways were considered to reduce this use and increase water available for other higher priority uses.

The demand for water by agriculture provided the impetus for a concerted effort by watershed specialists to evaluate the feasibility of increasing water yield on Arizona's major water-producing area, the Salt-Verde drainage above Phoenix. Their consensus was published as the Barr Report (Barr 1956). Limited experience in various parts of the country at that time indicated that converting forest cover to grass could increase water yield. Even less was known of the water potential in brushlands, although the studies in California were providing some positive results. As part of the Arizona Watershed Program, several experimental watersheds were established on National Forest lands to evaluate effects of manipulating vegetation, primarily for improving water yield. Only the studies conducted by the Forest Service in the chaparral will be discussed here. Other studies were made in juniper, pine, mixed conifer, and riparian vegetation by the Forest Service and other agencies.

Of the several vegetation types considered for treatment in the Barr Report, chaparral was given low priority because little improvement in water yield was thought possible on these sites. However, our studies have since shown strong water yield increases after chaparral conversion. On the other hand, conversions in the juniper type have shown little promise of increasing water yield (Brown 1971). It appears now that the chaparral potential was misjudged because its precipitation was generally underestimated. Precipitation in the chaparral was estimated in the Barr Report to vary between 14 and 18 inches; we now know that most of the chaparral gets more than 18 inches.

VEGETATION, SOIL, AND WATER RELATIONS

Vegetation

Chaparral in Arizona occurs mostly on rough, broken country south of the Mogollon Rim, extending generally in a discontinuous band across the central part of the State from northwest to southeast (fig. 1). The type occurs at elevations ranging from 3,000 to over 6,000 ft, depending on exposure, soils, and climate (fig. 2). The most extensive and continuous chaparral stands are found on or adjacent to the Prescott and Tonto National Forests, and on Indian lands in the Salt River basin. The upper margin of the chaparral borders ponderosa pine or occasionally pinyon-juniper stands, while the

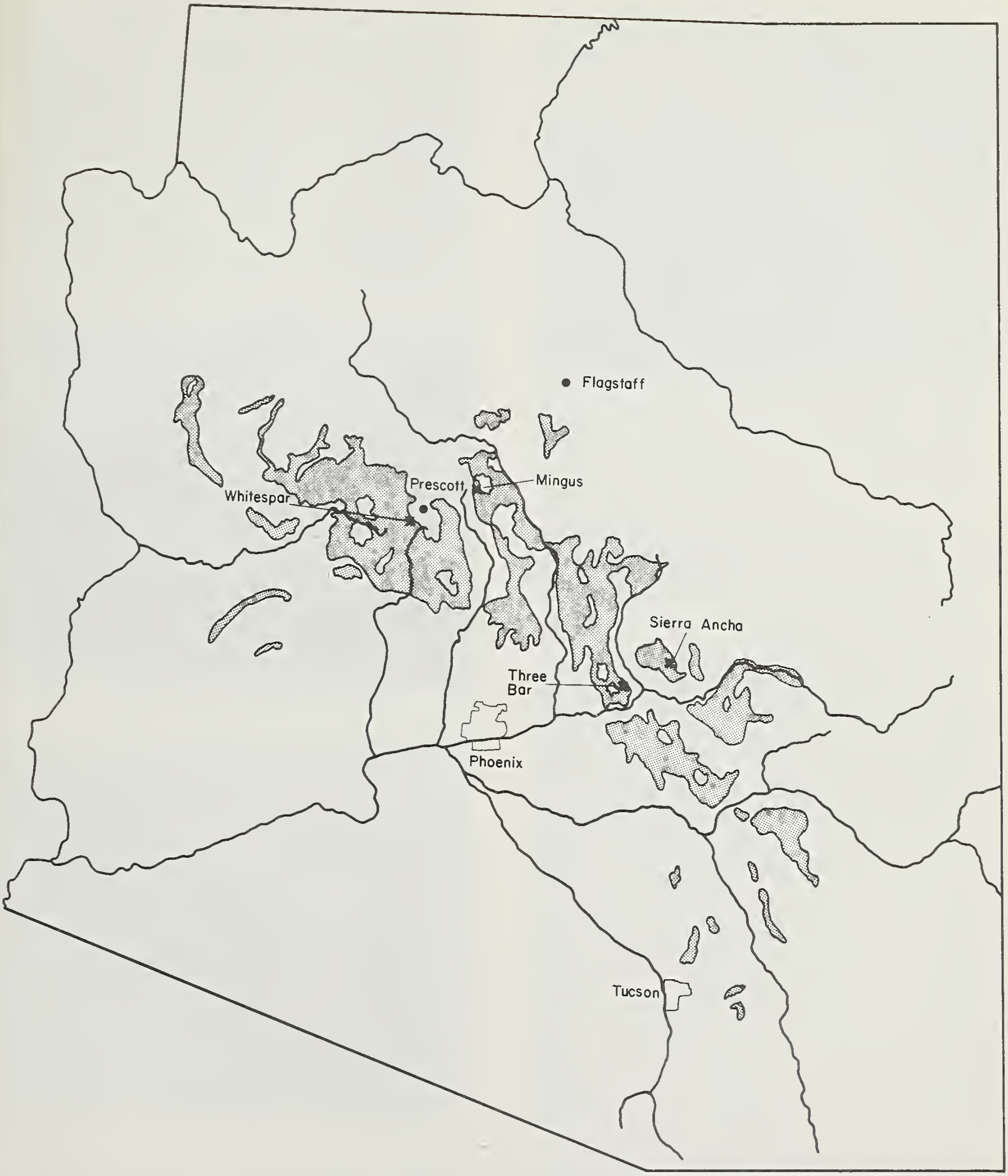

Figure 1. — Distribution of chaparral (Brown 1973) and location of experimental watersheds in Arizona.

Figure 2. — Mixed chaparral dominated by shrub live oak and true mountainmahogany on deeply weathered diabase soil at 5,000 ft elevation and 25 inches precipitation (Sierra Ancha Experimental Forest).

lower margin borders semidesert grassland or southern desert shrub. In southeastern Arizona, chaparral mixed with oak-woodland adjoins ponderosa pine on the flanks of a few isolated desert mountain ranges such as the Santa Catalinas (Lowe 1964).

The area covered by chaparral has been estimated as large as 8 percent (5.8 million acres) of the land area of Arizona by Nichol (1952). However, more recent surveys indicate less acreage. Spencer (1966), using USDA Forest Service survey techniques, estimated 3.7 million acres. A smaller acreage, 3.2 million acres, was determined by measuring chaparral areas shown on vegetation maps published by the University of Arizona (Humphrey 1963) and by the Arizona Resources Information System (Brown 1973). These differences in area, particularly between Nichol and the more recent surveys, reflect lack of common criteria for classifying chaparral. Both Nichol and Spencer include as chaparral extensive areas in the Southeast that are classified as woodland or encinal by Humphrey and Brown. Also, the lower margin of the chaparral type is so indistinct that many thousands of acres might be classified as either chaparral or desert shrub, depending on individual interpretation of species composition and cover density.

Since the more recent estimates are probably the most accurate, it is probable that chaparral covers considerably less than 4 million acres in Arizona. Of this acreage, a large proportion cannot be considered for treatment because it is classified as wilderness, it is too steep, its cover is too sparse, or for other reasons it is not suitable for conversion. These restrictions are discussed further in Part II in an economic analysis of conversion.

The chaparral community typically consists of moderately deep to deep-rooted, evergreen sclerophyllous shrubs that reach best development on deep soils or on deeply weathered or broken rock mantles (fig. 3). Most chaparral shrub species are prolific crown and/or root sprouters, and produce few seedlings (Pase 1969); the few nonsprouters produce abundant seed. The sprouting species live to considerable age; Pond (1971) found little change in individual plants after 47 years.

A

B

Figure 3. — A, Dense mixed chaparral, primarily Emory oak and Pringle manzanita, on deeply weathered granite soil at 6,000 ft elevation and greater than 25 inches precipitation (Tonto National Forest).
B, Medium to low density chaparral dominated by shrub live oak and hairy mountainmahogany on deeply weathered sedimentary rock at 6,000 ft elevation and 18 inches precipitation (Prescott National Forest).

The type is well adapted to fire. Because the well-developed root systems can exploit the moisture and nutrients in a large volume of soil, stands regenerate rapidly following fire (Pond and Cable 1962, Pase and Pond 1964, Pase and Lindenmuth 1971). Favorable weather conditions germinate seeds of nonsprouting shrubs, such as *Ceanothus* and *Arctostaphylos* species, which benefit from heat scarification. Such seeds may lie dormant in the soil for many years before the conditions necessary for germination occur (Pase 1965).

Shrub crown cover may vary from open (less than 40 percent) on xeric sites to dense (more than 60 percent) on favorable sites where moisture is less limiting. Under dense brush, herbaceous cover is virtually absent. Annual litter production was measured at 1 ton per acre under stands dominated by oak and mountain-mahogany (Pase 1972). Forest floor weights of more than 20 tons per acre were found under dense manzanita stands in central Arizona (Glendening and Pase 1964). Even greater accumulations may be possible; in southern California, Kittredge (1955) reported forest floor weights under chaparral of up to 50 tons per acre.

Compared with other vegetation types, the chaparral community consists of a relatively large number of species of diverse habit, usually dominated by one or more of the following species: shrub live oak (*Quercus turbinella* Greene), Palmer oak (*Q. chrysolepis* var. *palmeri* (Engelm.) Sarg.), Emory oak (*Q. emoryi* Torr.), birchleaf and true mountainmahogany (*Cercocarpus betuloides* Nutt. and *C. montanus* Raf.), pointleaf and Pringle manzanita (*Arctostaphylos pungens* H.B.K. and *A. pringlei* Parry), Wright and yellowleaf silktassel (*Garrya wrightii* Torr. and *G. flavescens* Wats.), desert ceanothus (*Ceanothus greggi* Gray), sugar sumac (*Rhus ovata* Wats.), skunkbush (*R. trilobata* Nutt.), hollyleaf buckthorn (*Rhamnus crocea* Nutt.), and Yerba-santa (*Eriodictyon angustifolium* Nutt.).

Where shrub canopy is open to moderately dense, grasses and forbs may be abundant in the intershrub spaces. Common grasses are sideoats and hairy grama (*Bouteloua curtipendula* (Michx.) Torr. and *B. hirsuta* Lag.), three-awns (*Aristida* spp.), cane bluestem (*Andropogon barbinoidis* Lag.), plains lovegrass (*Eragrostis intermedia* Hitchc.), green sprangletop (*Leptochloa dubia* (H.B.K.) Nees), wolftail (*Lycurus phleoides* H.B.K.,) and muhlys (*Muhlenbergia* spp.). Spring- and summer-growing annuals, abundant in favorable wet years, include red brome (*Bromus rubens* L.), witchgrass (*Panicum capillare* L.) and needle grama (*Bouteloua aristidoides* (H.B.K.) Griseb.). Common forbs include penstemon (*Penstemon* spp.), redstar morningglory (*Ipomoea coccinea* L.), dark spurge (*Euphorbia melanadenia* (Pursh) Britt. & Rusby), and bluedicks (*Dichelostemma pulchellum* (Salisb.) Heller). Common halfshrubs include Wright buckwheat (*Eriogonum wrightii* Torr.), broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britt. & Rusby), and rough menodora (*Menodora scabra* Gray).

While generally classed as forest, the chaparral type is considered noncommercial because little or no timber and wood products are produced. However, it is important habitat for several big game species, including mule and white-tailed deer and black bear. Water production is intermediate between the very low-producing desert areas below and the better-watered forest areas above. Forage for domestic livestock is fair in open chaparral but is sparse in dense stands of brush.

In general, as density of the shrubs increases, useful production declines, fire hazard and cost of control increases to high levels, and accessibility is severely restricted. Because of these features, the chaparral is somewhat unique in that most management practices that reduce stand density tend to improve productivity and accessibility.

Climate

The climate of central Arizona is marked by two rather distinct wet periods. Winters are cool and wet through March, followed by warm, dry weather for 2 or 3 months until summer rains start in July. Dry weather usually returns by October and persists until winter rains begin in November or December. Since most of the chaparral is located in the central part of the State, the discussion of climate and hydrology will be restricted to this area.

Mean annual precipitation ranges from about 16 inches at the lower limits of the chaparral to over 25 inches on the wetter sites. Precipitation generally increases with elevation, but not uniformly so; elevation of itself is not a good indicator of precipitation. The proximity of mountains and other physiographic factors that control flow and cooling of air combine with elevation to produce the local climate. Some snow falls each year, but normally snow is not an important factor in the hydrology of the chaparral type.

Roughly 55 percent of the annual precipitation falls as rain or snow between November and April. The moisture usually comes from the Pacific as frontal-type storms which become heavier as the moist air is forced over the central highlands. These storms may dump several inches of water in 24 hours, but their intensity is relatively low. Summer moisture from the Gulf

of Mexico in the form of local convection storms accounts for about 35 percent of the annual rainfall during July, August, and September. These storms are often intense and erratic, dropping as much as 3 inches of water in an hour. The remaining 10 percent of annual rainfall comes in May, June, and October, the driest months. The water year is calculated from the first of July to coincide with the end of a 2- or 3-month period of low hydrologic activity when the moisture regime varies the least from year to year.

Precipitation varies greatly in Arizona, both in space and time (McDonald 1960). Temporal variability is usually the most important in an arid environment because seasonal and annual extremes in rainfall, particularly on the dry side, profoundly affect the vegetation and the amount of water produced. Spatial variability, or differences in areal distribution of precipitation, presents less of a problem because land use and management practices can be more easily tailored to accommodate differences between sites than between years.

Mean annual precipitation is commonly used to describe the moisture regime of an area. In itself, however, the mean tells nothing about the frequency and seasonal distribution of rain, and little about the magnitude of dry and wet years, critical factors in the survival and maintenance of plant cover. Long-term records are scarce in the chaparral but available data suggest that the driest years receive about one-half the mean precipitation while the wettest years get about double the mean. Thus, in some marginal areas, as little as 8 inches of rain may fall in dry years while in very wet years the wetter sites might receive as much as 50 inches.

Arizona is also noted for its wide range in temperature, which is closely related to elevation (Smith 1945). Mean temperature is determined by averaging daily maximum and minimum readings. Within the chaparral zone, mean annual temperatures range between 50° and 65° F. Mean monthly temperatures may vary from less than 40° in January to more than 80° F in July.

Wind generally is out of the southwest. Average windspeed at 6 ft above the ground, about the height of the shrub canopy, varied from 30 to 112 miles per day over a 2-year period at four chaparral sites in central Arizona. At present we do not know the quantitative effect of wind on ET (evapotranspiration) on these sites, but it may be an important factor in the water balance. Potential ET is much greater than precipitation in the chaparral. Estimates vary between 45 and 60 inches, depending on climatic and physiographic factors. Class A pan evaporation averaged 74 inches per year at 5,100 ft elevation (Sierra Ancha Experimental Forest), and about 82 inches at 3,500 ft (Three Bar watersheds).

Soil, Geology, and Cover Relations

Soils supporting chaparral have certain characteristic properties throughout central Arizona. Typically, soils are deep, coarse textured, and poorly developed. Soil as used here includes all porous material (regolith) in which weathering and roots are active. The distinction between soil depth and solum depth (A and B horizons) is critical in this case, since most of the soil is in the C horizon. Soil surveys which describe the soil as shallow generally pertain to solum depth. Usually, the A horizon is only a few inches thick, and the B horizon is commonly absent. Soil texture varies from cobbly and gravelly loamy sand to gravelly loam.

Parent materials include deeply weathered and fractured granite, schist, diabase, and sandstone. Granites are found on more than half the total chaparral area, while diabase and sandstone comprise less than 10 percent. At the Three Bar experimental watersheds (figs. 1 and 4), coarse-grained granite was found by seismic exploration to be weathered and fractured 20 to 40 ft deep (Ackermann and Walters 1965). Roots of the dominant chaparral species penetrate these materials to as much as 30 ft, although the majority of roots are concentrated in the upper few feet of soil and in the numerous fractures cutting through the decomposing rock.

The C horizon is hydrologically important, even though total porosity may be only 20 to 25 percent. Because of deep weathering, this zone stores much winter rain, which the deep-rooted shrubs use during dry periods.

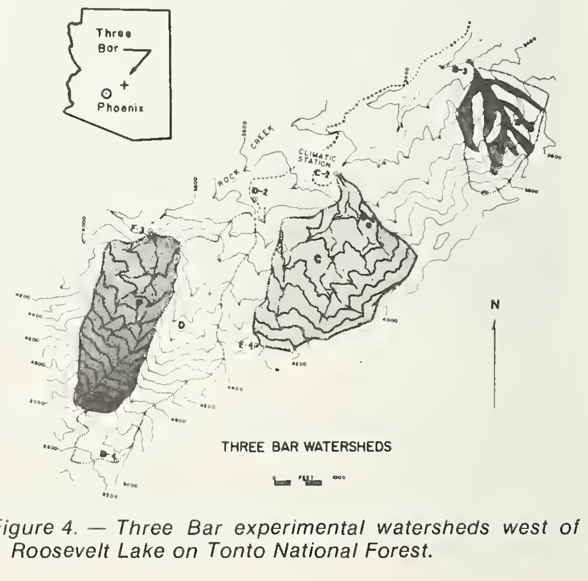

Figure 4. — Three Bar experimental watersheds west of Roosevelt Lake on Tonto National Forest.

Chaparral shrubs grow on a variety of geologic rock types, all of which weather to produce a deep, coarse regolith. In contrast, rock types such as basalt, limestone, and quartzite, which weather to relatively fine-textured shallow regoliths, normally do not support chaparral, even though rainfall and elevation are similar. These soils usually support juniper, pinyon, or grass. On the Sierra Ancha Experimental Forest, for example, shallow quartzite soils support grass with scattered shrubs, while adjacent soils derived from intrusive diabase support a medium-dense stand of brush. Other examples of brush on granite next to juniper on basalt can be found on the Tonto and Prescott National Forests.

The view that the distribution of these two vegetation types (chaparral and juniper) is more a function of soil than of climate and elevation has not been widely held. Juniper has traditionally been thought of as occurring at higher elevation and at an assumed higher rainfall zone than chaparral; the rainfall assumption, however, is not valid.

As an example, Utah juniper and alligator juniper stands dominate the central portion of the Beaver Creek drainage south of Flagstaff at elevations ranging from 5,000 to 6,500 ft where annual precipitation averages 18 to 20 inches. On the Mingus watersheds 30 miles to the west at similar elevation and precipitation, the dominant vegetation is chaparral with scattered juniper and pinyon trees. Soil is the only apparent difference in the sites that would account for the difference in vegetation. The soils on Beaver Creek are derived from basalt and are relatively fine textured and shallow, compared with the soils on Mingus which are derived from Precambrian sedimentary rock that is shattered and weathered to a greater depth. Farther to the southwest on the Whitespar watersheds, again at 6,500 ft, the chaparral is even better expressed on granite-derived soils, which appear to be somewhat deeper than at Mingus. Here precipitation is 22 to 24 inches, and brush gives way to ponderosa pine on the higher, more moist sites.

Water Relations

Streamflow

There are no large watersheds covered solely by brush. Since the environment for chaparral is favorable mainly along flanks of mountain ranges, most large drainages cross these "bands," extending into conifer above or semidesert below. Catchment areas lying entirely within the chaparral seldom exceed a few thousand acres.

Figure 5. — Streamflow gages on Whitespar B experimental watershed, Prescott National Forest. Medium to low flows are measured by the sharp-crested 120° V-notch weir; flood flows by the San Dimas flume.

Streamflow has been gaged (fig. 5) by the USDA Forest Service, and USDI Geological Survey on a number of small experimental watersheds ranging in size from 9 to about 3,000 acres. Mean annual water yield on these small watersheds varies from less than 0.1 inch per year on the drier sites to 2.5 inches on the wetter areas. An overall average yield for the brush type is difficult to ascertain from these data because the catchments are not necessarily representative of all of the chaparral in Arizona. By selecting data we consider most representative, we estimate mean yield to be 1.25 inches based on 22 inches of mean precipitation. This compares with earlier estimates of water yield in Arizona chaparral of 0.5 inch (Barr 1956) to 1.5 inches (U.S. Senate 1960).

Some of the water yielded by small headwater catchments is lost to riparian vegetation downstream, the proportion being larger in dry years than in wet years. The amount of the loss will vary according to length and type of stream course. Many of the intermediate-size watersheds, such as 119,000-acre Sycamore Creek near Fort McDowell, flow intermittently on the surface, although flow may continue in the channel alluvium. Surface flow in the upper part of Sycamore Creek is perennial, but in the lower part all surface flows up to about 200 ft^3/s (cubic feet per second) soak into the unconsolidated channel fill, which along the lower 9 miles is as much as 100 ft deep. Thomsen and Schumann (1968) estimate that some 4,000 acre-ft per year discharges to the Verde River through this alluvium.

The amount and seasonal distribution of streamflow depends largely on when and how much it rains. Most of the water is produced

during the cool winter months when ET is low and precipitation is relatively heavy. Despite high intensities, very little of the summer rainfall runs off. The proportion intercepted by the brush is larger because rains are smaller. That reaching the ground is absorbed readily in the upper few inches of soil, where it is quickly transpired or evaporated. Headwater streams often are dry by early summer, although recurrent heavy rains may sustain base flow at a low level throughout the summer.

The average seasonal distribution of yield from the four experimental sites in the chaparral is 85 percent in the November-April dormant season when 55 percent of the precipitation occurs, and 12 percent in July, August, and September with 35 percent of the rain (fig. 6). The three driest months (May, June, and October) account for the remaining 3 percent of the yield from 10 percent of the rain. In the Sycamore Creek drainage, Thomsen and Schumann (1968) found a similar seasonal distribution: The November-April period accounted for about 60 percent of the precipitation, but was responsible for 90 percent of the yield.

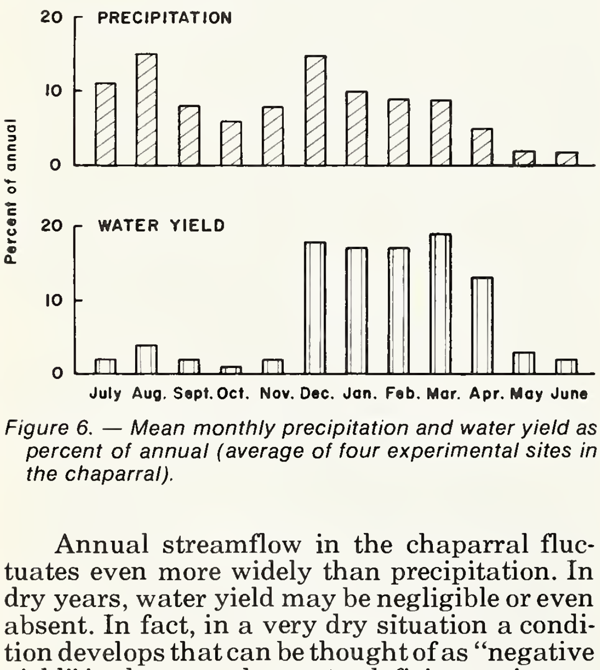

Figure 6. — Mean monthly precipitation and water yield as percent of annual (average of four experimental sites in the chaparral).

Annual streamflow in the chaparral fluctuates even more widely than precipitation. In dry years, water yield may be negligible or even absent. In fact, in a very dry situation a condition develops that can be thought of as "negative yield" in the sense that water deficits continue to increase after streamflow stops. Before streamflow (base flow) can resume, this deficit must be satisfied. Thus after prolonged drought (such as the winters of 1970-71 and 1971-72), a greater amount of recharge is necessary to attain a given flow level than in years with rainfall near normal.

While dry years produce little water, wet years, particularly wet winters, may yield 20 percent of precipitation or more in some areas. One wet year may produce runoff equal to several years of near-average precipitation. This relationship and its implications for improving water yield are discussed further in the section on water yield increases.

Plant-Water Relations

Chaparral occupies zones that are too dry for forests, yet receive sufficient rainfall to allow grass or deep-rooted woody plants to thrive. Water is the major limiting factor for plant growth; the deep rooting habit of chaparral shrubs enables them to survive periodic seasonal droughts. Both climate and vegetation in the chaparral favor large ET losses. Because ET accounts for such a large proportion of precipitation, water yield might be considerably improved if transpiration can be reduced. It is worthwhile, therefore, to consider some of the plant-water and soil-water relationships that would be modified by chaparral conversion.

Climate, aspect, plant, and soil affect ET. Climatic factors are precipitation, solar radiation, temperature, humidity, and wind. Aspect of the site influences the local climate, particularly solar radiation and temperature. The plant influences transpiration by its crown, leaf, and root characteristics, and by stomatal opening. Soil depth, texture, and permeability affect the supply and delivery of water to the plant roots. Since chaparral conversion involves changes in the plant cover, the factors of most importance are those associated with plant and soil.

The two rainy seasons in Arizona, combined with the broadleaved evergreen character of chaparral shrubs, present an interesting hydrologic situation. Because the shrubs are foliated year-round, they can transpire whenever atmospheric and soil conditions are favorable. The soil is recharged in the winter when precipitation is heaviest. Some winter transpiration undoubtedly occurs, although the rate is low because of cool temperatures. Summer rains break a long drought which lasts from early spring to midsummer. During this prolonged dry period, atmospheric conditions are favorable for high ET losses, and the soil moisture reserve is depleted. Summer rains seldom are concentrated enough to recharge the soil, although the moisture is important for plant growth. Any water in excess of immediate plant demands is drawn on during the dry fall months when the ET potential is still high. Consequently, early winter rains are utilized to recharge the soil mantle that dried in the preceding months.

Water availability to chaparral plants depends first on the water supply, and then on the amount of storage and depth of rooting in the soil. When the soil is only a few feet deep, the type of vegetation should not appreciably influence water yield unless there is a difference in length of season of water use or in transpiration rate. Short-lived annuals, for example, would be expected to use less water than perennials.

In deep, well-drained soils, the type of vegetation markedly affects water yield. Deep-rooted shrubs whose roots ramify the entire soil mantle can deplete the soil-water reserve to a greater extent than shallow-rooted grasses and forbs. Even the various shrub species may differ significantly. Other factors probably contribute as well. Interception of precipitation by brush is greater than by grass (Corbett and Crouse 1968); thus more water enters the soil under grass. Also, seasonal dormancy of grass, particularly during winter, results in less water withdrawal, and greater recharge below the grass rooting depth. Still other factors such as albedo, leaf structure, and stomatal behavior may cause water use by grass to be less, but most of the water savings are believed to result from water being less available to the shallow roots.

BRUSH CONTROL AND ESTABLISHMENT OF REPLACEMENT COVER

The eradication or suppression of brush is basic to chaparral conversions for improving water yield. Under natural conditions chaparral is well adapted, and will not be permanently reduced unless some form of brush control is practiced. Economical methods are available for controlling chaparral in some situations, but in many cases methods are either ineffective or too expensive for widespread use. Another problem is that no existing brush control herbicide is fully registered for use on watersheds (see the Pesticide Precaution Statement at the end of this report). Nor is the fate of the phenoxy herbicides clear at the present time.

A major challenge in chaparral control is the development of treatment prescriptions which are effective, economical, and safe to humans, wildlife, livestock, and aquatic life. Contamination of the watershed ecosystem (particularly stream water) with herbicides, or undesirable alterations of the nutrient composition of stream water as a byproduct of brush control, are hazards which must be seriously considered.

Chaparral control methods which have proved effective in Arizona include prescribed burning, mechanical methods, chemicals, and prescribed burning followed by chemicals. Many of the techniques used in southern California (Bentley 1967) may be applied here. However, California chaparral differs in species composition and summer moisture. Establishing perennial grass cover in central Arizona is enhanced by summer rains which account for about one-third of the annual precipitation.

Prescribed Burning

Prescribed burning (fig. 7) modifies the density, stature, and composition of chaparral. One advantage of fire is that the environmental changes it creates were also common in the evolution of the ecosystem. A disadvantage for most chaparral areas is that control is temporary. Therefore the objective must be suppression rather than eradication.

Figure 7. — Firing chaparral with hand-held torch during prescribed fall burning on Sierra Ancha Experimental Forest.

Not all chaparral shrubs respond similarly to burning (table 1). A fire-tolerant plant is one that rapidly recovers by sprouting even after repeated burns; a fire-susceptible plant does not sprout after its top is killed by fire, although fire may stimulate its seeds to germinate. Consequently, the site can be reoccupied by seedlings of the same species or by other species whose seeds were stored in the ground or carried in after the fire. A moderately fire-tolerant plant can be controlled by a limited number of burns 1 or 2 years apart. Shrub live oak, a fire-tolerant species, has an enormous sprouting capacity; in one test it survived six annual burns (Pond and Cable 1960). Manzanita, on the other hand, is fire susceptible.

Table 1.--Susceptibility of some Arizona chaparral shrubs to fire and low-volatile esters of phenoxy herbicides (brush killer [2,4,-D + 2,4,5-T], 2,4,5-T, or silvex)

Botanical and common names of shrubs	Susceptibility to-- Fire	Phenoxy herbicides	Remarks
Acacia greggii catclaw acacia	Tolerant[1]	Mod. resistant	Refoliates and/or resprouts from base
Arctostaphylos pringlei Pringle manzanita	Susceptible	Mod. susceptible	Spray when actively growing; nonsprouting
Arctostaphylos pungens pointleaf manzanita	Susceptible	Mod. susceptible	Do.
Berberis haematocarpa barberry	--	Susceptible	
Ceanothus greggii desert ceanothus	Susceptible	Susceptible	
Ceanothus integerrimus deerbrush ceanothus	Susceptible	Susceptible	
Cercocarpus betuloides birchleaf mountainmahogany	Tolerant[1]	Mod. resistant	Refoliates and/or resprouts from base
Cercocarpus breviflorus hairy mountainmahogany	Tolerant[1]	Mod. resistant	Do.
Cercocarpus montanus true mountainmahogany	Tolerant[1]	Mod. susceptible	Do.
Eriodictyon angustifolium yerba-santa	Tolerant[1]	Susceptible	
Garrya flavescens yellowleaf silktassel	Mod. tolerant[1]	Mod. resistant	Do.
Garrya wrightii Wright silktassel	Mod. tolerant	Mod. resistant	Do.
Mimosa biuncifera Wait-a-bit	Tolerant[1]	Mod. resistant	Do.
Quercus chrysolepis var. *palmeri* Palmer oak	Tolerant[1]	Mod. resistant	Do.
Quercus emoryi Emory oak	Tolerant[1]	Mod. resistant	Do.
Quercus turbinella shrub live oak	Tolerant	Mod. resistant	Do.
Rhamnus crocea hollyleaf buckthorn	Mod. tolerant	Mod. resistant	Do.
Rhus ovata sugar sumac	Tolerant[1]	Mod. susceptible	Resprouts from base.
Rhus trilobata skunkbush sumac	Mod. tolerant	Mod. susceptible	Do.

[1]Tentative classification.

Prescribed burning is done during periods of suitable and acceptable fire hazard which will assure the desired control, usually in fall or winter. Chemical sprays can be used to desiccate the brush and increase its flammability (Pase and Lindenmuth 1971), although such sprays may not always be effective or necessary on mature stands. More information and testing are needed to determine how desiccation affects intensity and patterns of burning. Brush can be desiccated with fast-acting contact herbicides such as diquat and toxic weed oils containing pentachlorophenol, or with slow-acting low-volatile esters of 2,4-D or 2,4-D plus 2,4,5-T.

The strategy for prescribed burning depends on the type of chaparral. Dense manzanita can be eradicated by a single burn, although its seeds will usually germinate profusely. If grass can be established before the manzanita seedlings gain dominance and again bear fruit, which requires several years, prescribed grass fires will eliminate the new shrub plants and perpetuate the grass. The oak-mountainmahogany complex includes many sprouting species, but normally is dominated by shrub live oak. A single burn followed by seeding of grass can achieve limited objectives, such as a temporary increase in water yield, forage, and

browse, or the reduction of brush density in critical areas as a precaution against wildfires. However, the sprouting brush rapidly recovers to near prefire conditions, and within a few years the temporary advantages are lost except that the stand will not readily burn again for several years.

Using repeated prescribed burns to kill brush and maintain conversion is sometimes dismissed as impractical because brush sprouts have such a competitive advantage over grass during the first few postfire years. After the first burn of mature brush, subsequent burns depend on an adequate grass cover to carry the fire. Very little research effort has been directed toward improving the method, however, despite its attractiveness as an alternative to the use of herbicides. Its success depends on rapid establishment of a grass cover so that a repeat burn fueled by grass is possible before the brush sprouts gain dominance over the grass.

Prescribed burning could be improved in several ways. Chaparral is normally burned during the fall or winter months when the wildfire hazard is low. Grass is established most successfully when the seeds are sown into the ashes soon after fire, but the commonly used lovegrasses germinate best if seeded just before the summer monsoons in late July and August. Perennial grasses are needed which will germinate during the fall and winter months to increase competition against the brush sprouts, and to provide immediate protection for the soil. Techniques are needed for establishing grass on steep slopes and for giving the grass a competitive advantage, perhaps through the use of fertilizers or biological controls such as goats to suppress sprout regrowth. More drought-tolerant and aggressive grasses are also needed. Seeded perennial grasses must be able to survive the effects of repeated burns.

Mechanical Methods

Mechanical equipment used to control brush includes rootplows, bulldozers, and brush crushers and cutters. Terrain is the major obstacle with all heavy equipment. Steep slopes and unusually rocky and gullied land often prohibit their use. Pond (1961) estimates only 2 to 8 percent of the chaparral is suitable for treatment with heavy equipment. Mechanical methods have the greatest potential on relatively level rangeland where forage production is the major objective. Their potential on steep headwater catchments is very limited.

Even on relatively level land, only the rootplow is adequate for eradicating chaparral because it kills the entire plant. Since other methods only reduce the overstory, their usefulness is restricted to preparing brush for burning and for temporary clearing operations such as fuel breaks. The rootplow is mounted behind a heavy tractor equipped with a bulldozer blade (fig. 8). The blade pushes the brush over and the rootplow is drawn 12 to 18 inches beneath the soil surface, severing root crowns from roots and lifting the root crown above ground to dry. The rootplow is limited to slopes less than 20 percent. Rootplow trials in the chaparral of Arizona have been conducted mainly on rangeland where shrub live oak predominates. Shrub mortality is usually 80 percent or more. Surviving shrubs were generally missed by the plow. With careful rootplowing it should be possible to achieve 90 percent or more brush reduction (Pond 1961, Pond et al. 1965).

All of the major shrubs on the low-elevation chaparral ranges can be controlled by the

Figure 8. — Rootplowing on Prescott National Forest. The blade is 12 ft wide and weighs approximately 2 tons. Seed is broadcast from rear of tractor.

rootplow. Yerba-santa, which sprouts from roots, regenerates to some extent if roots remain covered by moist soil. However, it is present in such limited amounts as to be unimportant. Retreatment of some kind may be necessary in manzanita if seedlings reinvade, but thus far reinvasion has not been a problem. Grass is usually seeded during plowing by mounting a seeder on the rear of the tractor.

Chemical Methods

Herbicides, properly used, can perform an important function in controlling chaparral on watershed lands. In large-scale projects greatest reliance has been placed on the phenoxy herbicides. Although when used alone they do not provide adequate control of some of the dominant chaparral shrubs, they have provided the only economical chemical method for treating large areas.

Chemicals Applied to Foliage

The most important of the foliage sprays are the phenoxy group of which 2,4-D (2,4-diclorophenoxyacetic acid), 2,4,5-T (2,4,5-trichlorophenoxyacetic acid), and silvex (2-(2,4,5-trichlorophenoxy)propionic acid) are the most commonly used. 2,4,5-T controls a greater number of species of woody plants than 2,4-D, but some plants are more susceptible to 2,4-D. Because most brush areas are composed of several species, commercial mixtures of 2,4-D and 2,4,5-T, called "brush killers," are commonly used. The dominant woody species in Arizona chaparral are affected most by 2,4,5-T and silvex (Lillie and Davis 1961, Davis 1962a, Lillie 1963). In general, they are about equally effective against shrub live oak.

A variety of formulations of these herbicides is available for brush control: low-volatile esters (propylene glycol butyl ether ester, butoxyethanol ester, and isooctyl ester), water-soluble and oil-soluble amines, and emulsifiable acids. Low-volatile ester formulations are the most effective for spraying brush, but they are more volatile than the other formulations, and may affect susceptible crops. Invert (water-in-oil) emulsions of phenoxy herbicides are particularly useful for minimizing the hazard of spray drift.

Foliage sprays can be applied by aircraft, mechanized ground rigs, or backpack mist blowers. Spraying by aircraft, particularly by helicopter (fig. 9), is the only practical or economical method for treating large watershed areas. Shrub composition, herbicide effectiveness, and cost are considerations in choosing the herbicide for a particular project.

The phenoxy sprays kill leaves and some stems. After the initial "brown-out," which is followed by various degrees of defoliation depending upon species, the bushes refoliate. If stems and branches are severely injured, most species will sprout from basal portions of branches and the root crown. Since a single spray suppresses growth only temporarily, repeat treatments are necessary. Poor penetration of low-volume aerial sprays through dense, mature canopies is partly responsible for limited success in reducing crown density. It is possible to cover top growth of fire sprouts more completely, and young sprouts are more susceptible than hardened woody stems.

For maximum effectiveness, foliage sprays of systemic herbicides must be applied at the proper stage of growth. Brush susceptibility is generally considered greatest after the spring flush of new leaves has reached maximum development, but before the leaves form a thick cuticle and are fully hardened. This stage corresponds to the time when transport of photosynthate to the roots begins. Since systemic herbicides are translocated with photosynthate, there is greater possibility of downward movement of herbicide at this stage. Plants are also most susceptible when growing under optimum conditions. Plants under moisture stress are less affected by herbicides.

Chaparral shrubs of Arizona differ in their susceptibility to phenoxy herbicides (see table 1). None can be classified as totally resistant. Susceptible species can be killed by a single treatment. Moderately susceptible species resprout and are killed by one or two treatments if conditions are optimal. Moderately resistant

Figure 9. — Helicopter applying herbicide spray to 1-year-old shrub sprouts on Three Bar watershed C.

species suffer leaf injury and stem dieback, but either refoliate or resprout from the root crowns; they are not eradicated by three or four annual sprays.

One of the chief advantages of the phenoxy herbicides is that they are selective; they are much more toxic to broadleaved plants than to grasses. Even though the phenoxy herbicides when used alone are inadequate for eradicating Arizona chaparral, repeated treatments can suppress the brush and eliminate some of the susceptible and moderately susceptible species. Unfortunately, the more resistant shrubs comprise the bulk of the brush cover. Substantial shrub mortality cannot realistically be expected until after the fourth or fifth annual applications.

Despite the marginal effectiveness of the phenoxy herbicides, they have nonetheless been used extensively to suppress brush in range and watershed improvement projects. Because of their selectivity and low cost, repeated treatments offer a method of tipping the ecological balance in favor of grass. Superior treatments are definitely needed.

Other chemicals applied to foliage include several substituted benzoic acid herbicides. An extensive survey showed 2,3,6-TBA (2,3,6-trichlorobenzoic acid) and dicamba (2-methoxy-3,6-dichlorobenzoic acid) to be the most effective benzoic acids on shrub live oak (Davis 1962b). Field investigations with foliage sprays of 2,3,6-TBA applied with ground equipment were encouraging (Lillie 1962b), but aerial applications were disappointing and considerably less effective than those with 2,4,5-T (Pase 1967).

Foliage sprays of picloram (4-amino-3,5,6-trichloropicolinic acid) are effective against many but not all chaparral species. To increase effectiveness, formulations containing picloram and 2,4-D are available which broaden the susceptibility spectrum. High-volume leaf-stem sprays have been more effective against resistant oak species than low-volume sprays (Davis 1964). Picloram or picloram-2,4-D sprays have shown little improvement over 2,4,5-T or brush-killer mixtures of 2,4-D and 2,4,5-T.

Soil Treatments

Herbicides in granular, pellet, or tablet form can be broadcast on the soil with aircraft, ground rigs, hand-operated fertilizer spreaders, or by hand. Hand applications are particularly suitable for spot treatment of low-density chaparral, or for selective treatment of brush. The method permits a great deal of diversity in application, and is adaptable to many vegetation management objectives.

From the standpoint of application, soil treatments have several advantages over foliage spraying. The greatest advantage is that water, oil, or other spray additives are unnecessary. Equipment requirements are fewer, and the entire procedure is simpler and more convenient. The problem of drift to nontarget areas is also eliminated.

In terms of plant response, the variability in seasonal susceptibility is not a problem with herbicides absorbed from the soil. The chemical should be applied in January or February when there is a good chance that rainfall will move the herbicide into the soil soon after treatment, in order to minimize possible losses through photodecomposition or volatilization.

Herbicides which are effective as soil treatments against chaparral are fenuron, picloram, karbutylate, and bromacil. Of these, only fenuron has been registered for range use; none is registered for watershed use.

Fenuron (1,1-dimethyl-3-phenylurea) has been used with considerable success against chaparral when applied either as a spot treatment by hand or as a broadcast application from helicopter (Davis and Lillie 1961, Lillie 1962a, Davis and Pase 1969). It is not equally effective against all chaparral shrubs, but fortunately the dominant shrub live oak is one of the most sensitive species (Davis and Pase 1969). Broadcast application rates of 8 to 16 pounds active ingredient (ai) per acre are necessary. Since fenuron is toxic to both grass and brush, broadcast application must not be repeated to avoid damage to newly established grass. Individual bushes or clumps of bushes are effectively treated by scattering fenuron pellets at the rate of 20 pounds (ai) per acre on the ground beneath bushes.

Picloram is herbicidally active either as a soil treatment or as a foliage spray. Although soil treatments are more effective than low-volume sprays against shrub live oak (Davis 1964), the oaks are less susceptible to soil-applied picloram than other chaparral species (Davis and Pase 1969). Spot treatments of 10 pounds (acid equivalent) (ae) per acre are needed to achieve 90 percent or more control of shrub live oak.

An important advantage of picloram is that it is less toxic to grasses than any other potential brush control chemical except for the phenoxy herbicides. Although picloram offers considerable promise for controlling chaparral, it has not been registered for range or watershed use in Arizona, and cannot, therefore, be recommended at this time.

Karbutylate (*m*-(3,3-dimethylureido)-phenyl-*tert*-butylcarbamate) is a new, nonselective, soil-applied chemical which is active against a wide variety of woody plants,

grasses, and forbs. Oak species as well as all other chaparral shrubs are susceptible, some more so than others. Nonsprouting species such as manzanita and ceanothus are particularly sensitive; they respond rapidly to soil treatments as soon as rainfall moves karbutylate into the root zone. Topkill is complete in several weeks. Because sprouting species such as shrub live oak and mountainmahogany go through several cycles of refoliating and/or resprouting it may take 2 to 3 years before they succumb. During this time, top injury is severe, and transpiratory water loss is reduced accordingly. Yellowleaf silktassel is one of the most resistant shrubs, but it is a minor component of mixed chaparral.

Spot treatments and broadcast applications of karbutylate applied at the rate of 20 pounds (ai) per acre give essentially complete brush control in mixed chaparral. It appears that broadcast applications of 8 pounds (ai) per acre will effectively control shrub live oak, but higher rates may be required to eradicate some of the more resistant species.

Karbutylate is persistent in soil. Phytotoxic residues from an application of 20 pounds (ai) per acre may remain in the top 6-inch layer of soil for 3 years or more. Herbicide persistence is desirable for controlling sprouting shrubs but undesirable for establishing a grass replacement cover soon after treatment to prevent soil erosion.

There are several possible ways to circumvent the effect of persistent soil residues of karbutylate on sown grasses. One way is to decrease the dosage of broadcast applications and accept a lower level of brush control. Lower dosages would permit grass to be established sooner. A better way may be to apply karbutylate in the form of large tablets spaced 3 to 6 feet apart. Preliminary evidence indicates that brush can be controlled by broadcast treatments with widely spaced tablets that allow grass to grow in the spaces between tablets. Where hand applications are feasible, the spot treatment of individual bushes and clumps would permit grass establishment in the intershrub spaces.

Karbutylate is not presently registered for range or watershed use. If and when it is, the possibilities for manipulating chaparral vegetation will be improved.

Bromacil (5-bromo-3-*sec*-butyl-6-methyluracil) is a potent, nonselective, soil-applied herbicide that has proved effective for controlling chaparral. Like karbutylate, it is persistent in soil. Phytotoxic residues exist for 3 years or more after applications of 10 pounds (ai) per acre. The problem of establishing grass after treatment, and possible solutions, are the same as those discussed for karbutylate.

Spot treatments of 10 pounds (ai) per acre give nearly complete control of the major oaks (shrub live oak and Emory oak), but only moderate control of mountainmahogany. Hollyleaf buckthorn is resistant. In general, bromacil is more active on chaparral shrubs than fenuron, and is about comparable to karbutylate. It is not presently registered for watershed use.

Prescribed Burning Followed by Chemicals

Prescribed burning with followup chemical treatments is an accepted method for converting brush to grassland. Burning the brush serves three purposes: it eliminates the dense overstory; stimulates the development of sprouts, which are more easily controlled than mature brush by presently used foliage sprays; and prepares a seedbed for sown grass seed. The use of fire in conjunction with spraying of sprouts has been more successful than either fire or sprays alone. Some of the new soil-applied herbicides promise better control than the phenoxy sprays when used in combination with fire.

Since fire is not a necessary step in the control program, the decision of whether or not to burn can be based on factors other than brush control, such as the desirability of opening up the area quickly, esthetics, seedbed preparation, or the consequences of fire. Some advantages of not burning prior to chemical control are the continued protection afforded by standing or fallen dead brush, retention of litter and soil organic matter, and maintaining high infiltration capacity of the soil. Some disadvantages of not burning the brush prior to chemical control include the unpleasing appearance of dead brush, and a high fire hazard until dead leaves are dropped. Also, grass is usually more easily established when the seeds are sown directly into the ashes after burning. Improved seeding techniques may be needed for establishing grass on areas of dead brush.

HOW CONVERSION AFFECTS WATERSHED RESOURCES

Treatments Applied and Vegetation Response

As part of the Arizona Watershed Program, several experimental watersheds were instrumented on National Forest lands to evaluate the effects of chaparral conversion. Treatments have been made in dense chaparral (greater than 60% crown cover, Three Bar),

medium dense (40 to 60%, Whitespar), and open or low density (less than 40%, Natural Drainages).

Three Bar Watersheds

These four watersheds (see fig. 4) are west of Lake Roosevelt in the Three Bar Wildlife Area, maintained cattle-free for game management studies. Elevation is 3,300 ft at the B weir where precipitation averages about 21 inches. Precipitation increases to about 28 inches at the top of watershed D at 5,200 ft where chaparral species intermingle with species of the oak-woodland and pine types. Parent material is coarse granite, exposure is northerly, and the upper slopes are steep, often exceeding 60 percent. Dominant shrubs are shrub live oak, birchleaf mountainmahogany, sugar sumac, and Emory oak.

Stream and rain gages were installed in 1956. Streams were intermittent, flowing about one-third of the time during the first 3 years, and yielding less than 1 inch per year average flow. In June 1959, the Boulder wildfire swept over all four watersheds, topkilling all shrubs. Shrub crown cover, which averaged 60 to 75 percent when the watersheds were established, was reduced to near zero by the fire (fig. 10). Where not subsequently treated, the brush has since

Figure 10. — Three Bar experimental watersheds before and after wildfire in June 1959. The second photo was taken 3 months after the fire, the third at the end of 3 growing seasons, the fourth after 8 years, and the fifth after 15 years.

recovered to about 90 percent of its prefire crown cover (fig. 11), although the biomass has not yet reached this level. Little herbaceous cover is present where brush is dense. Grass is present in the more open stands such as south slopes, but is sparse elsewhere.

After the wildfire, all watersheds except C were seeded with weeping and Lehmann

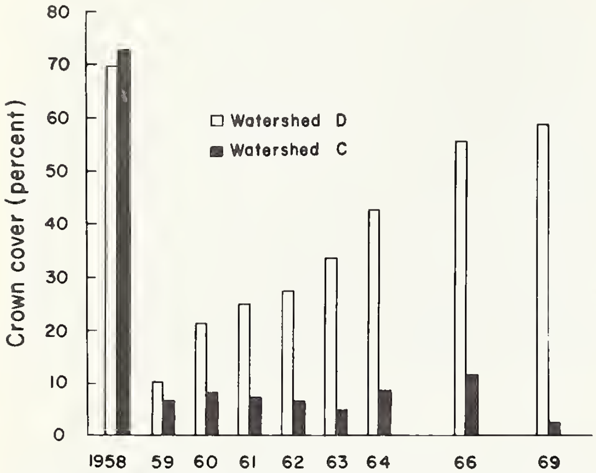

Figure 11. — Shrub cover on Three Bar C and D before and after the 1959 wildfire. Shrub recovery on C was suppressed with herbicides. Cover measurements were made at the end of the growing season of the calendar year indicated.

lovegrasses *(Eragrostis curvula* and *E. lehmanniana)* and yellow sweetclover *(Melilotus officinalis)* in July 1959, but the catch was very poor. Watershed B was seeded again and C for the first time in May 1960 with weeping, Lehmann, and Boer lovegrasses *(E. chloromelas)*. The resulting fair but spotty catch has gradually increased in density where shrubs have been controlled.

After the fire, watershed D (80.5 acres) was allowed to recover naturally as the control, and watersheds B (46.5 acres), C (95.3 acres), and F (68.4 acres) were subjected to various chemical treatments (table 2).

Although wildfire was not intended to be part of the original study, plans were realined to accommodate the burning as part of the treatment on watershed C. Thus, treatment on C is properly described as wildfire followed by conversion to grass using chemicals to suppress the shrubs.

The four annual aerial spray treatments on watershed C suppressed shrub regrowth, but actually killed only 42 percent of shrub live oak and 72 percent of birchleaf mountainmahogany plants. Hand treatment of surviving shrubs in 1964 and again in 1968 resulted in much better control. By 1969 shrub crown cover had been reduced to less than 3 percent. Figure 11 shows the degree of control on watershed C and shrub recovery on watershed D. Grasses and forbs on C averaged 1,200 lb/acre/year from 1963 to 1968

Table 2.--Chemical treatments and dates applied following a June 1959 wildfire on the Three-Bar watersheds B, C, and F (watershed D was used as a control, and not chemically treated)

Treatment method	Chemical	Rate of application	Watershed and year treated		
			B	C	F
		lb./acre			
Helicopter spray entire watershed	2,4,5-T	1.6		1960	
		1.6		1961	
		1.6		1962	
		1.6		1963	
Hand applied to surviving shrubs	Pelleted fenuron	3.6		1964	
Hand applied to individual shrubs on 40% of watershed:					
16.4 acres	Pelleted fenuron	18.3	1965		
2.1 acres	Granular picloram	9.3	1965		
Hand applied to surviving shrubs					
18 acres	Pelleted fenuron	6.1	1968		
70 acres	Pelleted fenuron	5.4		1968	
22 acres	Granulated karbutylate	4.4		1968	
Helicopter application, entire watershed	Granular karbutylate	20			1969
Hand applied to individual shrubs on remaining 60% of watershed	Pelleted karbutylate	6.7	1972		

(fig. 12). Ground cover is good to excellent over most of watershed C (fig. 13), and surface infiltration rates have remained high. The channel area in particular is well vegetated by weeping lovegrass. Cover is poorest on the upper, steep north exposures where lovegrasses have not done well. Forbs and half-shrubs provide fair ground cover on these sites, which account for perhaps 10 percent of the catchment. Livestock has not grazed Three Bar since 1947.

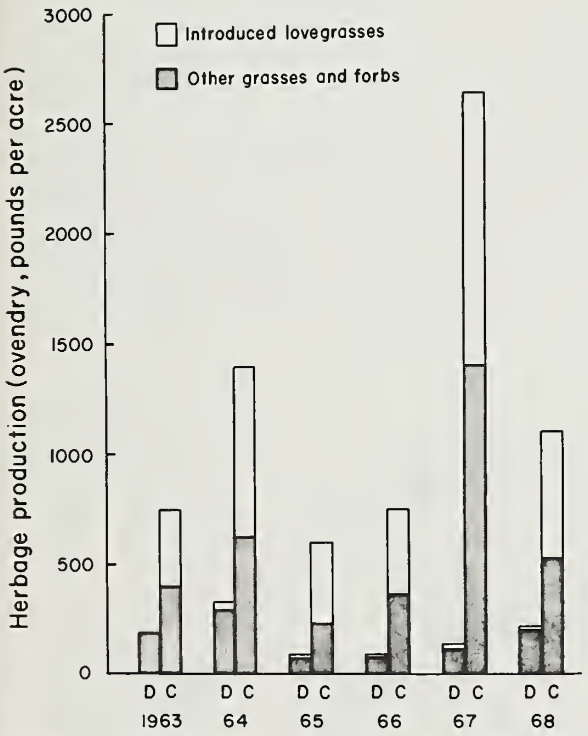

Figure 12. — Herbage production on Three Bar watersheds D and C for calendar years 1963 through 1968.

Figure 13. — Scattered shrubs persist in Three Bar C (to right of ridgeline), but ground is well covered by introduced grasses and forbs.

Watershed C was control burned in March 1971. A similar study on the use of fire for maintaining grass dominance after conversion had been made 2 years earlier on a nearby plot with good results (Pase 1971). Topkill of shrub live oak and birchleaf mountainmahogany, the two most numerous shrubs remaining on watershed C, was 71 and 68 percent. Grass was stimulated to higher production than without burning. There was no evidence of surface runoff or erosion as a result of the burn.

Shrubs on northeast-facing slopes comprising 40 percent of watershed B (see fig. 4) were hand treated in 1965 after 6 years recovery following the wildfire. Surviving shrubs were again treated in 1968. Browse plants of highest wildlife value were not treated; these species made up only about 5 percent of the total shrub cover, and included hollyleaf buckthorn, desert ceanothus, and false-mesquite *(Calliandra eriophylla)*. The two treatments reduced shrub cover to about 8 percent. In spaces between shrubs, damage was light to forbs and grasses, which responded to release from shrub competition. Grass and forb production has averaged 690 lb/acre/year on the treated area, but only 300 on the untreated slopes.

The remaining 60 percent of watershed B (untreated portion, fig. 4) was treated in January 1972 in the same manner as the 1965 treatment, except that the chemical applied was karbutylate formulated as 50 percent active ingredient tablets spaced a foot or so apart on the ground surface around each shrub. After two growing seasons the treatment appears successful, although evaluation is incomplete.

Watershed F was treated in February 1969 with a broadcast application of granular karbutylate to the soil. Shrub crown cover was reduced from 55 to 4 percent in the first year. The shrubs began showing visual effects of the chemical by late April. Injury symptoms progressed rapidly during the spring months, and by early June most of the shrubs were either dead or dying. Total shrub kill increased to more than 95 percent after 2 years. Virtually all grasses and herbaceous plants also were killed by the treatments.

Phytotoxic residues remained active in the top 6 inches of soil over most of the catchment for the first 2 years, preventing growth of new plants. The only exception was along the lower channel where flow surfaced and became perennial after the treatment. A variety of forbs and grasses dominated by horseweed *(Erigeron canadensis)* invaded the channel area, where the plants rooted in the bed of the stream or in the moist banks. This band of vigorously growing plants was only a few feet wide, and ended abruptly where water was not within a few inches of the soil surface. None of the plants

showed any effects of chemical poisoning as on the rest of the watershed.

During the third growing season (1971) forbs and grasses began to appear on interior ridges in the lower part of the watershed, but many of these showed injury symptoms before fall. Invasion by forbs and grasses during the fourth growing season finally produced fair cover over all but the upper 10 to 15 percent of the watershed.

For more detailed information on treatments at Three Bar, see: Glendening et al. 1961, Pase and Ingebo 1965, Pase 1967, Pase et al. 1967, Davis and Pase 1969, Ingebo 1969, Smith et al. 1969, Hibbert 1971, McCulloch, 1972, and Davis and Ingebo 1973.

Whitespar Watersheds

The Whitespar watersheds are located about 7 miles southwest of Prescott in the headwaters of the Hassayampa drainage. The parent soil material is fine-grained granite, elevation is 5,800 to 7,000 ft, precipitation is 23 to 25 inches, and the exposure is southeast. Watershed A (303 acres) is slightly higher than B (246 acres), receives slightly more precipitation, and yields slightly more water (1.8 to 1.3 inches). Streamflow tends to be somewhat more flashy on Whitespar than on Three Bar, suggesting less storage capacity in the regolith. Gaging began in 1958.

The chaparral on the Whitespar watersheds is considered medium dense, averaging 51 percent crown cover on watershed B. Shrub live oak and true mountainmahogany are abundant. Scattered alligator junipers *(Juniperus deppeana)* to 4 ft in stem diameter are found mostly along drainageways and lower slopes. At this elevation (5,800-6,700 ft), patches of Gambel oak *(Quercus gambelii)* are common on cool northerly slopes. Cover in the channel bottoms is largely an extension of shrub types found on adjacent slopes. Herbaceous plants are sparse; annual production is less than 50

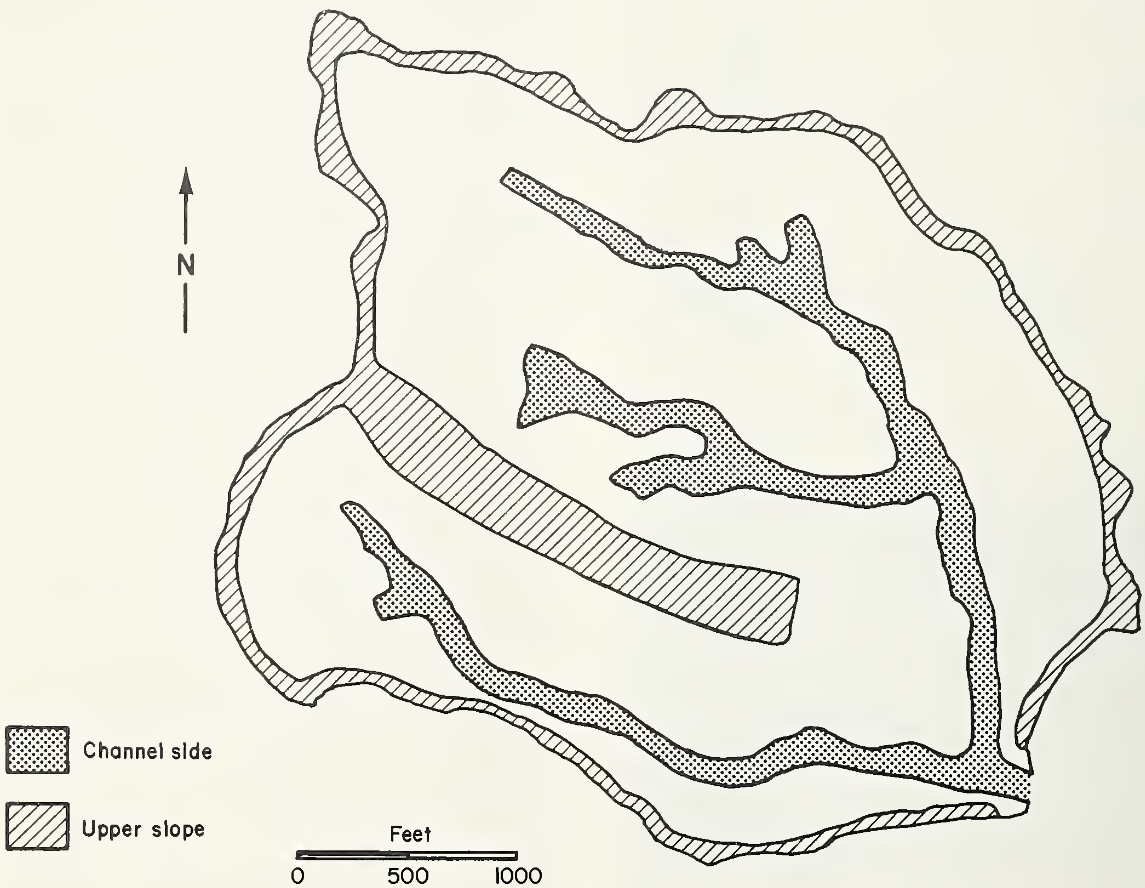

Figure 14. — Whitespar watershed B on Prescott National Forest about 7 miles southwest of Prescott. The channel-side treatment was made in 1967, the upper slope treatment in 1973.

lb/acre, about equally divided between grasses and forbs.

Conversion of channel-side brush cover to grass on B (fig. 14) was the first of a series of treatments to eventually convert the entire watershed. The second treatment was made in 1973 to convert an area of similar acreage on the upper slopes in a strip surrounding the watershed just inside the boundary to simulate a fuel break. The third and fourth treatments will convert the remaining area by southerly and northerly aspects separately.

The intent of the first treatment was to eliminate all shrubs and juniper trees that use water from the moist channel environment. By eliminating these plants, water concentrating downslope along the stream channel would be subject to less transpiration loss before contributing to the stream. Bounds of the treated zone were set at 30 ft vertical but no more than 75 ft horizontal distance from the channel. Cover in the zone was not typically "riparian;" no sycamore, alder, cottonwood, or other species often found along streams were present.

The treatment covered 38 acres, 15 percent of the watershed. Pelleted fenuron (25 percent active ingredient) was placed by hand underneath shrubs and small junipers in March 1967. Intershrub spaces were not treated to avoid killing grasses and forbs. The average rate of application on the 38 acres was 23.2 pounds (a i) per acre. Larger junipers were either cut or girdled. The single application of fenuron gave 80 to 90 percent control of the shrubs; retreatment has not been necessary. The native grasses and forbs have increased substantially on the treated area, providing generally good cover except in the patches of Gambel oak where establishment of grasses and forbs has been slow. Cattle graze both watersheds, although B was fenced after treatment to control grazing.

During the second and particularly the third summers after treatment, flannel mullein (*Verbascum thapsus*) flourished along the moist channel bottoms (fig. 15). By the fifth growing season these plants were no longer numerous. What effect this rank growth might have had on water yield is not certain. Since flow increased throughout these years, however, it is apparent that the vigorously growing weeds did not consume as much water as the brush.

For more complete details of treatments and treatment response, see Ingebo 1971, Hibbert and Ingebo 1971, and Ingebo 1972.

Natural Drainages

The four Natural Drainage watersheds (fig. 16) are designated A (13.4 acres), B (19.5 acres), C (12.1 acres), and D (9.1 acres). The original vegetation type on the watersheds was marginal chaparral, which became quite sparse and open on the more southerly exposures and on the fine-textured quartzite soils on the lower slopes. The upper slopes are diabase soils, which cover 42, 54, 44, and 28 percent of the four watersheds, respectively. Before treatment, crown cover of shrubs was 20 to 25 percent compared with covers twice to three times this dense on Whitespar and Three Bar. Shrub live oak was most abundant.

Livestock first appeared in the general area about 1880, but grazing was brought under strict control in 1934 when gaging began. The drainages were first used to study the effect of grazing on runoff and erosion. These studies

Figure 15. — Flannel mullein in the channel-side treatment area on Whitespar B third summer after the shrubs were killed.

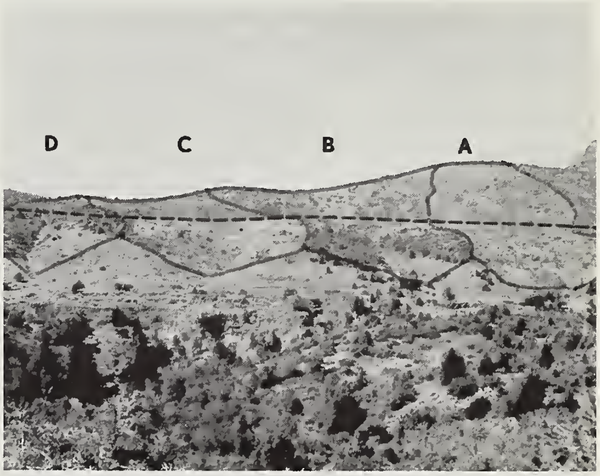

Figure 16. — Natural Drainage watersheds in 1960, 5 years after treatment on watersheds A and C. Dashed line shows contact between diabase parent material above and quartzite below.

were completed in 1952, when it was found that the intensities of grazing used in the studies had no significant effect on total water yield and sediment trapped in the weir ponds (Rich and Reynolds 1963).

Starting in 1954, the chaparral cover was eradicated to study the influence of conversion on streamflow. The basal 6 inches of each shrub on watersheds A and C was sprayed with a 6.6 percent solution 2,4-D and 2,4,5-T in diesel oil until the outer bark was saturated. Half-shrubs were not sprayed. Surviving shrubs were resprayed as necessary. Drainages B and D were left untreated as controls. By 1959, grass cover on the treated quartzite soils was about three times greater than before treatment. No significant change was noted on the diabase soils. Forbs and half-shrubs increased on all treated sites, with the greatest gain on diabase soils. The study was completed in 1971.

Changes in Streamflow

Streamflow Prolonged by Treatment

One of the more remarkable effects of brush conversion is that summer flows are prolonged well into or through dry periods. At Three Bar, the once-intermittent streams now flow yearlong on all three treated catchments. Watershed C, which was dry two-thirds of the time prior to the wildfire, has flowed continuously since. Flow in control watershed D was also prolonged after the wildfire, although it again became intermittent as brush regrew.

Three Bar B yielded no water before the wildfire. It flowed continuously after the fire for about 18 months, then was intermittent until 40 percent of the catchment was treated in 1965. Flow has been continuous since. Watershed F responded similarly, although here flow reacted more quickly to treatment. The chemical was broadcast in February 1969, and shrubs began showing injury symptoms in late April. Beginning in May, streamflow held above the expected flow rate based on the control catchment. By mid-May, flow on F was twice the expected rate, and by the end of June the difference was even larger.

This rapid response on F is important to water management interests. Streamflow responded within 3 months after chemical application, and within a few weeks of the first observed injury symptoms on the shrubs. Apparently, chemical suppression of plant activity reduced transpiration which allowed streamflow to increase. Since rainfall in this period was not enough to materially affect yield, the extra flow presumably came from stored moisture in the regolith that would have been returned to the atmosphere had the shrubs remained fully active.

Similar behavior in streamflow was noted by Crouse (1961) on the San Dimas Experimental Forest in southern California after wildfire burned a partially treated chaparral watershed (Bell No. 2). Chemical suppression of shrubs prior to the fire on 40 acres of the 100-acre catchment had materially increased yield and had created perennial flow in the normally intermittent stream. The fire in July 1960 burned all remaining vegetation. Two months after the fire, flow was 280 percent of that expected had the area not burned.

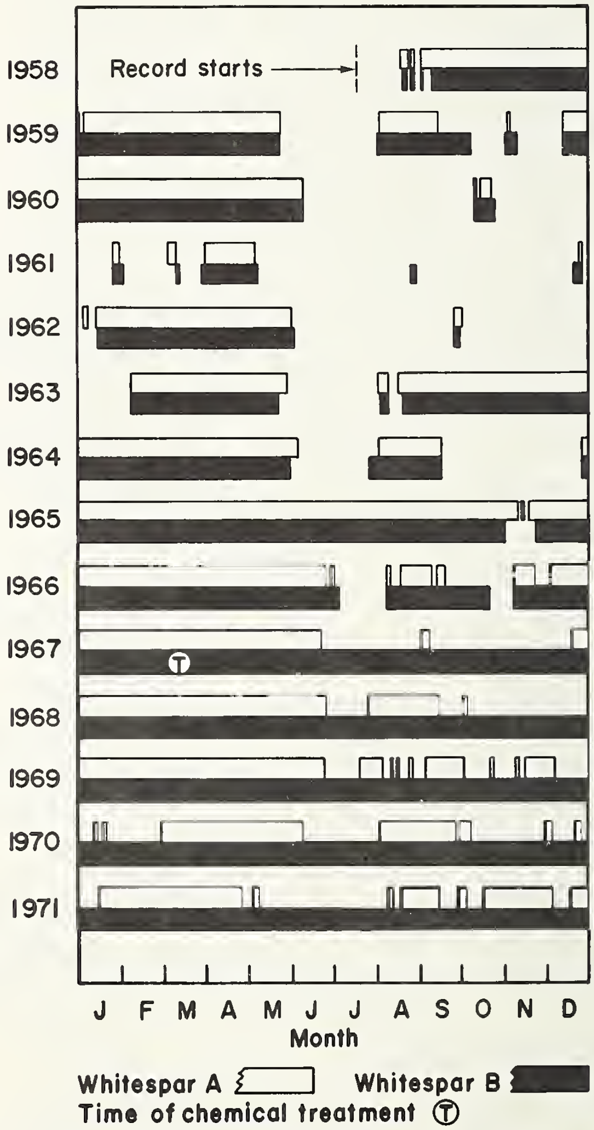

Figure 17. — Flow duration on Whitespar watersheds before and after the channel-side treatment on B in March 1967.

Flow in Whitespar B likewise became continuous after treatment of 38 acres of channel-side brush in 1967. While these lingering dry-season flows are too small to be of practical significance downstream (several years would be required to yield an acre-ft of water at the lower flow rates), they are important sources of water for wildlife and livestock. Pools persisted at intervals along the channels of B long after watershed A had dried completely (fig. 17).

Treatment did not create perennial flow in the Natural Drainages, although it is possible that duration of flows was prolonged.

Water Yield Increases

Without exception, water yield on each watershed increased after treatment. The increases were largest on Three Bar and smallest on Natural Drainages. Some of these results have been published: Three Bar B and C (Pase and Ingebo 1965, Hibbert 1971); Whitespar B (Ingebo 1971, 1972); and Natural Drainages (Ingebo and Hibbert, in preparation). Table 3 summarizes all experimental results through July 1972.

After the wildfire at Three Bar, an obvious sharp increase in overland flow was noted from the first summer rains, which were much heavier than usual that year. Although accurate measurement of stormflows in the first 2 postfire years was hampered by overtopping and sedimentation of the stream gages, it was apparent that both storm and nonstorm flows were materially increased by burning. The effects of the burning on water yield largely disappeared within 3 years on watersheds allowed to regrow to brush, although some increase persisted for several years.

We conclude from these results that water yield responds to burning as it does to other methods of reducing shrub cover, but the gains quickly diminish as the brush recovers. On watershed D, crown cover at the end of the third year was one-third of its prefire density (see fig. 11), apparently enough to effectively nullify earlier gains.

Unlike the control, watershed C continued to yield water at a rate more than four times that expected without treatment. In 11 posttreatment years (omitting the first 2 years after fire), measured yield on C averaged 7.55 inches, an increase of 328 percent or 5.78 inches more than the expected yield (1.76 inches).

Water yield on Three Bar B under 40 percent conversion since 1965 averaged 320 percent or 1.28 inches greater than expected. Prorating the increase would indicate 3.20 inches more from the 40 percent of the watershed actually treated. While it is reasonable to prorate the increase to the area actually treated, it is not correct to assume that the remainder of the watershed would respond to treatment at the same level, since the first treatment was on the more moist sites.

Water yield on Three Bar F increased 703 percent or 2.67 inches during 3 years after chemical treatment in 1969, even though these 3 years were drier than average. We expect larger volume increases from wetter years, although the percentage increase may actually decline.

On Whitespar B, the channel-side conversion on 38 acres (15 percent of the watershed) increased yield by 66 percent or 0.53 inch. These results are comparable to Three Bar experience when prorated to the area actually treated. Here, obviously, the most favorable sites were treated. We expect a lower level of response from future treatments on the upper slopes.

Table 3.--Summary of average increases in water yield for the years following treatment on each watershed

Watershed	Watershed area	Portion treated	Treatment period	Mean precipitation	Mean annual increase and 90 percent confidence interval	
	Acres	*Percent*	*Years*	*Inches*	*Percent*	*Inches*
THREE BAR:						
C	95.28	100	[1]11	23.91	328 ± 96	5.78 ± 1.69
B	46.52	40	7	20.60	320 ± 50	1.28 ± .20 [2](3.20)
F	68.39	100	3	[3]22.66	703 ± 440	2.67 ± 1.67
WHITESPAR:						
B	246.4/	15	5	20.42	66 ± 16	.53 ± .13 [2](3.53)
NATURAL DRAINAGES:						
A	13.41	100	17	17.78	23 ± 25	.25 ± .27
C	12.14	100	17	17.78	35 ± 10	.52 ± .15
A + C COMBINED	25.55	100	17	17.78	28 ± 14	.37 ± .18

[1]First 2 years after wildfire omitted.
[2]Amount prorated to portion of watershed actually treated.
[3]All 3 years drier than average.

Combined, the two treated Natural Drainage catchments averaged a 28 percent increase, or about one-third inch of extra water per year. Unfortunately, the Natural Drainages are representative of only a small portion of the chaparral in Arizona because of the shallow quartzite soils on the lower portions of the catchments. These soils are sparsely covered by brush, and probably contribute little, if any, extra water when treated. It is possible that most of the increase in yield comes from the upper portions of the catchment where the deeply weathered diabase is more typical of chaparral soils.

Two graphs based on the relationship between water yield and precipitation are presented for predicting yearly and average response to chaparral conversion. Reliability depends on how well the experimental sites represent the chaparral in general. The input data are dominated by Three Bar, particularly watershed C, in the high-response range, and by Natural Drainages in the low range. Very likely, conditions are near optimum at Three Bar for increasing yield and near minimum at Natural Drainages.

The first graph is derived by regressing yearly increases (difference between measured and predicted yields on all experimental watersheds) on yearly precipitation. Giving equal weight to all of the data, leads to an average treatment response curve (fig. 18). This relationship indicates how the onsite yearly increases vary over the range in annual precipitation so far experienced on the experimental watersheds.

The wide variation of the observed increases suggests the difficulty of precisely predicting individual annual response to treatment. The amount and seasonal distribution of rain interact with cover, soil, and site factors peculiar to each area to produce the observed responses. The tendency for wet years to produce a disproportionate amount of water has practical significance in management of these watersheds. In exceptionally wet years when natural yield exceeds storage capacity of downstream reservoirs, extra water produced by treatment does not have the same value as in dry years when the amount of the increase is much less and is needed more. Annual precipitation in the chaparral does not follow a normal distribution. Years with below-average precipitation occur almost twice as frequently as years above average, although the wet years yield more. In a year one-third wetter than average, the expected yield increase will be about eight times greater than in a year one-third drier than average. As extremes in wet and dry years are approached, the difference becomes much larger. In a year 50 percent wetter than average, the expected increase is 31 times greater than in a year 50 percent drier than average. In 37 years (1935-71) at Natural Drainages, for example, 1 year fell in each of these latter categories.

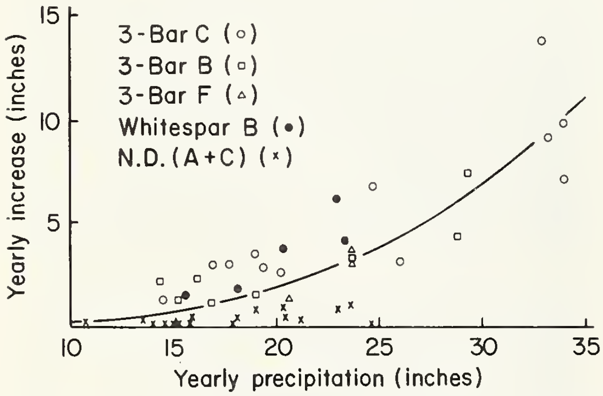

Figure 18. — Yearly increases (difference between measured and predicted yield) plotted against yearly precipitation for all treatment years on all watersheds. Three Bar B and Whitespar B data are prorated to area actually treated.

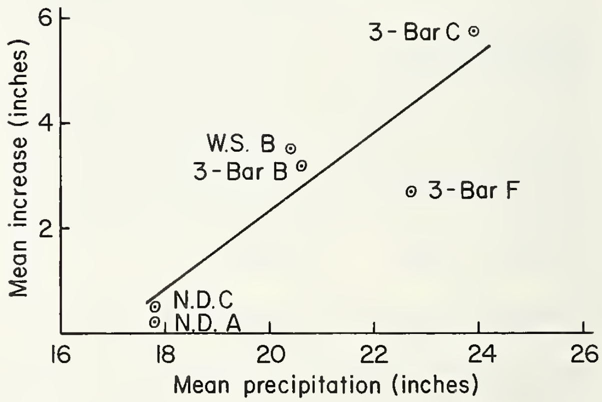

Figure 19. — Mean annual increase in water yield as function of mean precipitation. Three Bar B and Whitespar B data are prorated to area actually treated.

We therefore developed a graph (fig. 19), which is more useful for planning purposes because it estimates the mean or "normal" response to treatment expected over a period of several years. Reliable estimates of mean precipitation can be obtained for chaparral areas in Arizona from the isohyetal map of Normal Annual Precipitation prepared by the U.S. Weather Bureau and published jointly by the Arizona Agricultural Experiment Station and the University of Arizona Institute of Atmospheric Physics.

The regression is given by

$$\overline{\Delta R}=0.74\ \overline{P} - 12.53$$

where $\overline{\Delta R}$ is mean annual increase in runoff and $\overline{P}$ is mean annual precipitation. Assuming 22 inches of precipitation, an approximate mean for chaparral in Arizona, the estimated $\overline{\Delta R}$ is 3.8 ±2.5 inches (90 percent confidence interval).

Some discounting may be necessary when extrapolating these onsite research results to larger areas where treatment may not be as complete or as continuous as on the experimental areas. On the small experimental watersheds, treatment was continuous on the slopes to the channels. If vegetation is left along the channel or between the channel and treated areas upslope, onsite yield increases will be smaller. The loss to downstream riparian vegetation is discussed in the next section on seasonal distribution.

To assure as much uniformity as possible between treatments, the original prescriptions called for reduction in shrub cover to less than 10 percent on the areas receiving treatment (vertical crown projection of surviving shrubs after conversion should not be more than 10 percent of the ground surface). This is not the same as reducing the shrub cover by 90 percent, unless the mature stand was 100 percent to begin with. If, for example, the original stand was 60 percent, a reduction to 10 percent would eliminate 83 percent of the shrub crown cover. Furthermore, a given level of reduction in crown cover does not necessarily mean that plant numbers are reduced by the same proportion. For example, many shrubs that are not killed outright by herbicides have crowns that are much reduced in size and function. In most of the treatments, the cover eventually was reduced to considerably less than 10 percent. Even where posttreatment cover was 8 percent on Three Bar B, many of the surviving shrubs were not healthy, and their transpiration potential was reduced.

The degree of shrub reduction is vitally important to success in improving water yield. Removing 50 percent of the shrubs in a thinning operation may give little or no increase, because each remaining plant will use more water. As thinning progresses, the rate of water use by individual surviving shrubs will approach a maximum (Campbell and Pase 1972) as physiological factors of the plant become more important in limiting transpiration than moisture supply. The effect of this relationship on water yield is hypothesized in figure 20, in which onsite increase is depicted as a curvilinear function of percent shrub removal. While the shape of the curve is highly descriptive, it illustrates the importance of removing most of the shrubs if substantial increases in yield are to be achieved.

Complete removal of shrubs on a conversion site (the portion actually treated) may not be practicable or desirable for various reasons such as cost, esthetics, or wildlife. However, it must be recognized that if water is the major objective, the conversion effort may be largely wasted unless more than three-fourths of the shrubs are eliminated. Water yield on the Three Bar control watershed, for example, was nearly back to normal 3 years after the wildfire, when shrub regrowth had reached only about one-third prefire crown cover.

Seasonal Distribution of Increased Yields

While the opportunity for increasing onsite water yield appears good, there is concern that the extra water may be lost to vegetation along stream courses draining the converted areas. Streams originating in the chaparral frequently flow through miles of semidesert before reaching rivers or storage reservoirs. These streams typically have narrow, incised channels on or near bedrock bordered by narrow bands of riparian vegetation. As the streams emerge onto lower, flatter terrain, broad meandering channels develop on flood plains of coarse alluvial outwash. During the hot summer months, transpiration by riparian vegetation is high as long as water is readily available to these plants. The streams usually flow each winter, but flow drops off in the spring, often ceasing during summer and fall except for occasional flash flows from summer storms. Appreciable streamflow usually does not recur

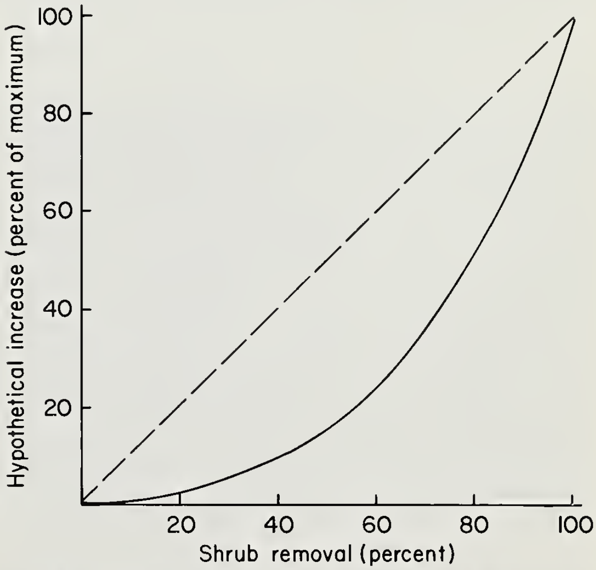

Figure 20. — Hypothetical water yield increase as function of shrub removal.

until winter rains recharge the drainage system. Subsurface flow may continue in the alluvium long after surface flow stops; in many of the channels subsurface flow is perennial.

Chaparral yields water largely in the winter and spring. About 85 percent of the water yield from the untreated experimental catchments is concentrated in the 6 winter months, November through April (see fig. 6). Sycamore Creek above the Fort McDowell gage drains 119,000 acres, about half of which is chaparral where most of the water is produced. Winter flows in Sycamore Creek make up 90 percent of the total yield (Thomsen and Schumann 1968). Other streams, such as the Hassayampa and Agua Fria north of Phoenix, yield two-thirds or more of their water in winter.

This predominately winter distribution of water yield is the key factor in realizing benefits downstream from cover conversion in the headwaters. If the yield increases also are concentrated in the dormant season, we can expect most of the extra water to be "carried through" on flow already present. Adding more water should not appreciably increase the evapotranspiration loss. Only when input is less than demand, as in dry winters or during the summer and fall, do we expect appreciable loss of the extra input.

After treatment we find that the proportion of water yield in the dormant period is much the same as before treatment, but the amount is greatly increased (fig. 21).

In most watersheds where chaparral conversion is feasible, we estimate that 80 percent or more of the increase in water yield will pass through the drainage system to storage or points of use. To arrive at this figure we assumed that very little of the winter flow increase (78 percent) would be lost, but that a substantial part of the summer increase (22 percent) might be taken up by downstream vegetation. At the present time, this estimate cannot be substantiated by measurements in the field, nor can we claim that the foregoing generalization applies to all areas.

In some types of drainage systems, a smaller proportion of the flow increase may be saved. In a low-yielding watershed, for example, where winter runoff does not normally recharge the alluvial aquifers each year, an increase in flow must first satisfy deficits along the stream course before yield can increase significantly. With water more readily available for a longer time to phreatophytes along the stream course, water use would increase at the expense of the extra water produced by treatment. It follows that, in very dry years when yield increases are small, little or no water may reach the outlet. For the most part, however, available evidence indicates that most of the extra water will get through in spite of riparian vegetation. Obviously, removal of riparian vegetation in combination with chaparral conversion would increase yields most.

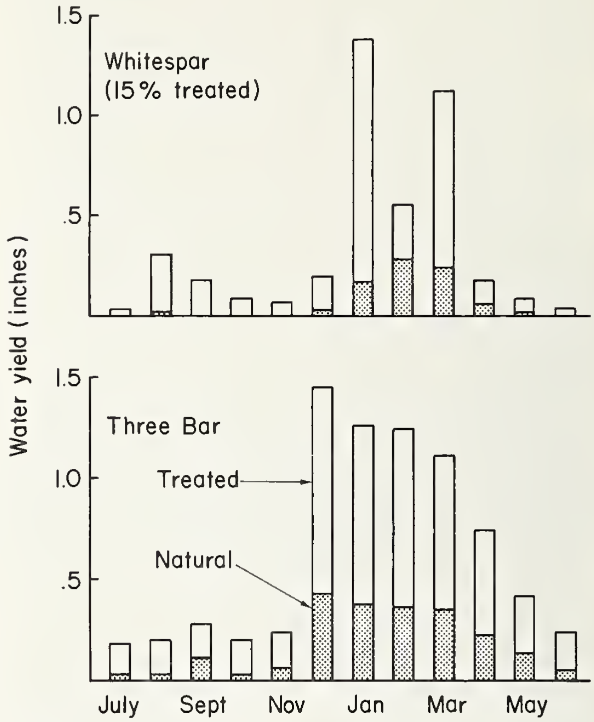

Figure 21. — Mean monthly water yield in inches on Three Bar C and Whitespar B. The upper portions of the bars denote treatment effect, which is in addition to yield that would occur without treatment. Whitespar data are prorated to channel-side area actually treated.

Erosion Following Fire and Conversion

Effects of conversion on erosion and sediment production are not readily predictable. Sediment production has been monitored on the experimental watersheds, but information is incomplete on processes causing erosion and sediment movement within the catchments and downstream.

Wettability

The extent to which infiltration is restricted because of nonwettable properties in chaparral soils under natural, burned, and treated conditions is not well known. It is common knowledge, however, that wildfire creates a very unstable soil condition, after which water runs off the surface much more readily than before. Slope erosion and scouring of headwater channels are greatly accelerated, and flooding

and sedimentation of downstream channels are expected. It is easy to demonstrate water repellency by clearing away the ash from a burned soil and placing drops of water on the mineral surface (fig. 22). The time required for the drops to infiltrate provides an index of wettability. But how does this relate to the runoff and erosion problem? Does the nonwettable layer persist long under the impact of rainfall? Which is the most important in causing overland flow and erosion, wettability or the loss of protective cover and organic matter?

Figure 22. — Drops of water fail to infiltrate mineral soil after wildfire that was hot enough to melt the beer bottle.

Scholl (1971) has demonstrated how wettability varies under an undisturbed Utah juniper stand at Beaver Creek. Resistance to wetting in the surface soil increased from completely wettable in openings between trees to highly nonwettable in the litter under the juniper canopy. It is noteworthy that one of the most intensely rilled areas found on the Whitespar watersheds after an exceptionally intense July storm was under the canopy of large spreading alligator juniper trees.

Findings in southern California by Forest Service and University scientists complement our studies on wettability of different aged stands of chaparral at Three Bar. Additional information should be gained on how wettability varies with local soils, species composition, and treatment or land-use practices such as grazing. With the present emphasis on grass conversion, it seems likely that numbers of cattle will be increased to match the increase in forage. Information is not complete on how cattle grazing may affect areas converted to grass. The effect of increased compaction and dislodgment on these steep, unstable soils, regardless of cover condition, warrants further study.

Sediment Yield

Because these soils are coarse, much of the sediment moved by the small headwater streams may be classed as bedload. If suspended by turbulent flow, the coarser particles quickly settle when velocity slows. Fine silts and clays which stay in suspension longer account for only a small percentage of total sediment. Bedload and some of the suspended sediments are trapped and measured in the weir ponding basins or sometimes in specially constructed sediment basins below the stream gages. Suspended sediment is sampled by one-shot samplers, by splitting devices, or by infrequent grab samples.

Soil moves off the slopes either by dry creep (fig. 23) and mechanical dislodgment, or by overland flow of water (fig. 24). Sometimes

Figure 23. — Soil creeping down an unstable slope on Three Bar watershed F, 4 years after treatment.

Figure 24. — Overland flow on this 2-month-old burned area carried considerable soil off the slope.

overland flows generate sufficient momentum on the slopes to start rilling, but then dissipate before reaching the channel, or if sufficient to reach the channel where the slope is less they dissipate there. By these processes, the headwater channel system accumulates sediment (fig. 25) until heavy flows flush it on downstream. Further downstream where channel gradients flatten, velocity of flow decreases and the coarse sediments are left to form broad alluvial fills.

Alternate cutting and filling occurs along the channel system as discharge rate and sediment supply fluctuate (fig. 26). The prime mover is the big storm; because these storms are rare, however, the long-term average or "normal" rate of erosion is difficult to determine. Short-term records of sediments trapped at some point in the watershed can be misleading. Sediment yield data collected in conjunction with our watershed experiments (table 4) must be evaluated with this limitation in mind.

A

B

Figure 25. — A, A small headwater channel just after wildfire, and B, the same channel 2 months later after summer rains filled the channel with sediment from nearby slopes.

Figure 26. — Alluvial deposits in channel on Three Bar watershed F cut by 8-inch storm in September 1970.

Sediment produced during the first 3 years after the wildfire at Three Bar contrasts sharply with production in the years before and after this period, and with the other watersheds where no fire occurred. Some of the accelerated production came from the channels where sediments had accumulated, perhaps for years. However, much of it came directly off the slopes as evidenced by severe rilling in portions of the catchments. The total yield for the first 3 postfire years on Three Bar watersheds D, C, and B combined was 1,083 ft^3/acre, or 25 times the 43 ft^3/acre measured during the other 13 years (3 prefire and 10 postfire). The occurrence of much greater than average precipitation in the first postfire year, including several intense summer storms, no doubt contributed to the high sediment production. However, equally wet periods and even more intense storms were recorded during the other 13 years, including the September 5, 1970 storm. Of significance here is the fact that the area was particularly vulnerable to erosion from heavy rainfall for only a few years after the fire. This conclusion applies to treated and untreated areas alike.

When dealing with long-term erosion rates, the rare climatic event must be considered. However, it is difficult to assess the impact of a 100- or 500-year storm, especially if it should come just after a burn. The storm of September 5, 1970 was classed as a 100-year or greater storm over much of central Arizona (Thorud and Ffolliott 1973). We do not know if it reached this magnitude at Three Bar, where rainfall was 8 to

Table 4.--Sediment, in ft^3/acre/year trapped in ponding basins at or just below stream gages on experimental watersheds (suspended sediment not included except that which settled in larger basins)

Water year ending in June of year shown	THREE BAR				WHITESPAR		MINGUS			NATURAL DRAINAGE		STRIP BURN	
	D[1]	C	B	F	A[1]	B	C[1]	A	B	B+D[1]	A+C	D[1]	A+B+C
										[2]3.8	[2]2.6		
1955										4.6	2.7		
1956										[3]T	.7		
1957	0	1.1	0							.9	.6		
1958	0	0	0							1.2	.7		
1959	0	0	0		0	0	[4]21	[4]0	[4]3.7	.7	.1		
1960	933	406	1238		0	.6	4.2	0	0	.2	T		
1961	102	64	321		0	0	0	0	0	T	T		
1962	274	64	259		0	0	16	0	13	0	0	0	0
1963	.6	.3	0		0	0	0	0	0	0	0	0	0
1964	.1	.3	49	1.4	.3	T	0	0	0	8.4	.9	0	35
1965	12	1.6	34	24	.4	1.0	0	2.9	5.5	.8	T	0	0
1966	6.8	24	18	14	T	1.0	0	2.1	4.8	9.3	.2	0	45
1967	.1	.2	2.0	T	T	.6	0	0	0	2.4	.4	0	18
1968	T	2.0	6.2	T	0	.2	0	1.9	8.7	0	T		
1969	.1	T	.3	0	0	.3	.2	0	0	0	0		
1970	.1	.1	.2	.2	0	0	0	0	0	.6	0		
1971	T	.1	.3	[5]59	0	0	.4	0	0	1.0	.2		
1972	0	.2	.3	34	0	0	0	0	0				
Mean	83	35	121	15	T	.3	3.0	.5	2.6	1.8	.4	0	16

[1]Control watershed.
[2]Mean annual sediment yield for period 1936-54.
[3]T = Trace = less than 0.1 ft^3/acre/year.
[4]Part of July 1958 not included; unknown amount of sediment occurred.
[5]Short by unknown amount that overflowed basin during storm of September 5, 1970.

10 inches. The most impressive thing about the storm at Three Bar was the lack of erosion. Despite heavy flows, the only watershed to produce sediment at the gaging site was the most recently treated watershed F, where more than 60 ft^3/acre came from the channel and slopes. The lack of sediment from the other catchments is attributed to lack of overland flow and stable channel conditions, particularly in the lower portions of the catchments.

The treatment on Three Bar F has shown that chemical control of vegetation can lead to substantial erosion on steep, unstable slopes. No erosion was detected on the catchment until 18 months after the treatment, which killed virtually all plant cover. Starting with the big storm in September 1970 (water year 1971 in table 4), sediment production remained heavy during most of the moderate to heavy rains through 1972. Sediment production was heaviest during October 1972 (not in table 4) when rainfall exceeded 14 inches on the watershed. At least 20,000 ft^3 (300 ft^3/acre) came out of watershed F. More than half of this came from the channel, as indicated by channel cross sections. The remainder came primarily from the steep upper slopes comprising about 10 percent of the watershed where vegetation has not recovered.

Control burning in contour strips can also produce sediment, although exposing only a portion of the slope each year to fire reduces the impact of broadcast burning. Three small catchments on the Sierra Ancha Experimental Forest were treated with prescribed fire in early fall for 4 consecutive years beginning in 1961. One-fourth of each catchment was burned each year in either 50-, 100-, or 200-foot-wide strips. A fourth catchment was left undisturbed as a control. The objective was to test prescribed burning in strips to temporarily reduce chaparral cover for improving water, forage, and browse production (Pase and Lindenmuth 1971).

Sediment moved off the treated slopes on three occasions during the treatment and evaluation period (table 4), twice during periods of heavy summer rains, and once during the wet months of November and December 1965 when

rain and snow totaled 17.2 inches. No erosion or overland flow was observed on the control catchment.

Sediment yield did not vary consistently with strip width, probably because of differences in slope, which appeared to be more influential in causing overland flow and rilling on the burned areas. Residual litter and relatively low burning temperatures were important factors in controlling sediment yield. Erosion was less noticeable on lightly burned areas where 70 percent or more of the litter residue was retained than on areas where less than 60 percent was retained.

Mass Slippage after Conversion

Mass soil slippage is not common in Arizona chaparral in contrast to certain portions of southern California where this form of soil erosion occurs after heavy storms and is accelerated by burning brush or converting to grass (Rice et al. 1969, Rice and Foggin 1971). Two probable reasons for less mass slippage in Arizona are slope steepness and rainfall. While generally thought of as being steep, most chaparral in Arizona is on gentler terrain than the problem areas in California, where most slips occur on slopes greater than 80 percent. Rainfall also is lighter in Arizona; both the size and frequency of storms are less.

A small soil slip did occur, however, on treated watershed C at Three Bar during the wet winter of 1972-73 after prolonged rainfall. The soil mass was 24 ft wide, 80 ft long, and about 3 ft deep. It moved enmass about 75 ft down a short, 65 percent slope near the upper ridgeline of the watershed. Wildfire in 1959 followed by grass seeding and chemical control of shrubs had converted the slope cover to mostly forbs and grasses.

The question of importance here is whether or not treatment was the primary cause of the slippage. If the event was largely the result of an atypically unstable soil mass being saturated to the point of slippage by prolonged, heavy rains, then the phenomenon will recur only rarely, and it need not be of particular concern. On the other hand, if treatment of the shrubs was the major cause of the soil mass becoming unstable under the abnormally wet conditions, then mass slippage may become a distinct hazard associated with treatments on steep slopes.

Summary of Erosion Effects

In summarizing treatment experience to date, it seems probable that most management practices will increase erosion for a time following chaparral conversion. The increase is likely to be greatest from broadcast burning, and least from mechanical or chemical eradication of shrubs if replacement cover is established soon after treatment. The experimental evidence at Three Bar shows that conversion to grass after wildfire does not reduce erosion any more than allowing brush to recover. Sediment production on Three Bar watersheds C and B over the past 10 years did not differ significantly from the brush-covered control. Since cattle have not grazed Three Bar, these cover conditions should be near optimum.

Over the long run, however, conversion should reduce erosion because the wildfire cycle will be interrupted and the heavy postfire erosion reduced or eliminated (Boster and Davis 1972). Safe grazing and other land-use practices must be strictly followed, however, to assure that the replacement cover will protect the soil at least as well as brush.

Chemical Contamination and Nutrient Changes in Stream Water

Chemical Contamination

The suitability of herbicides depends on many factors in addition to their effectiveness in controlling brush: toxicity to wildlife, livestock, and humans; persistence in soil; susceptibility to leaching; and effects on grasses, irrigated crops, and the products of streams, lakes, and reservoirs. The relative importance of these factors varies with the chemical. The problem is further complicated by factors such as location; size of area treated; the frequency, rate, type, and season of application; soil properties; topography; and precipitation. In some cases it may be necessary to regulate the size of treatments closely to avoid the buildup of residues in water supplies.

Picloram content of stream water from Three Bar B (46 acres) was monitored after a spot-treatment application in early February of 19.5 pounds (ae) of picloram in pellet form to 2.1 acres in a small side drainage (Davis and Ingebo 1973). Rain shortly after the treatment flushed some of the chemical through the soil and into the main stream channel. Concentrations of 350-370 p/b (parts per billion) were measured during the first 3 months after periods of heavy rainfall. Concentrations were much lower than this most of the time. Picloram was no longer detectable after 14 months and 40 inches of accumulated

rainfall. Considerably higher contamination levels would be expected if picloram were applied over the entire watershed. Since the side drainage represented only 4.5 percent of the watershed, there was a possible 22-fold dilution of the chemical. An estimated 4.5 percent of the picloram applied was lost to stream water.

On the basis of present toxicological data, this treatment would not represent a hazard to humans, wildlife, or aquatic organisms. Although direct use of water from the treated watershed when picloram levels are 46-370 p/b could damage sensitive crops such as cotton, dilution with water from untreated areas would reduce picloram to harmless levels.

A spot treatment of fenuron on 18 acres of Three Bar B (40 percent of the watershed) resulted in very low stream water contamination for 18 months. Fenuron pellets were applied by hand in January to individual bushes and clumps of bushes at 20 pounds (ai) per acre. The overall application rate on the treated slopes was 6.1 pounds per acre. For the first 6 months, concentrations fluctuated from zero to 7 p/b. During the following winter, fenuron concentrations reached 11 p/b after several heavy rainstorms. After 18½ months and 31 inches of precipitation, fenuron was no longer detected.

It is estimated that only 0.11 pound, or 0.1 percent of the 112.5 pounds of applied fenuron left the watershed in the stream water. Because fenuron has a very low toxicity rating, the type of treatment applied has an extremely low contamination potential.

Fenuron was monitored on Whitespar B after spot treatment of 23 pounds (ai) per acre on 38 acres of mixed chaparral along the major stream channels. Shrubs were treated 75 ft either side of the channel. The highest concentration detected in the stream water was 420 p/b, 33 days after treatment following heavy rains. Subsequent concentrations ranged from 50 to 280 p/b during the first year, and from 8 to 40 p/b during the second year. Cumulative rainfall was 27 inches the first year and 50 inches for both years. Trace amounts of fenuron or its breakdown products were still present in the stream water 27 months after treatment, but not after 3 years.

An estimated 21.3 pounds, or 2.4 percent, of the 884 pounds of applied fenuron left the watershed via streamflow. Although trace amounts persisted for a long time, the relatively small loss of fenuron from a treatment area adjacent to the stream channel again indicates that fenuron has a low contamination potential.

Granular karbutylate was broadcast by helicopter in mid-February to Three Bar F (68 acres) at the rate of 20 pounds (ai) per acre. This application gave nearly total brush kill. In the future, lower rates might be found to give adequate brush control, but for this study the high rate was used to insure brush eradication. The study will provide data on extent and duration of stream water contamination caused by a maximum application rate.

Weekly water samples were analyzed throughout the first year; more frequent samples were analyzed during the first month and during periods of heavy rainfall. Method sensitivity for karbutylate in water was 10 p/b. Water samples taken at the V-notch weir immediately after the application was completed contained 22 p/b karbutylate, presumably from granules falling on a short stretch of surface streamflow immediately above the weir. During the first year the concentration of karbutylate never exceeded 51 p/b. Concentrations ranging from 11 to 51 p/b were present in 15 out of 59 samples. Fourteen of the fifteen samples containing detectable residues occurred within 4 months of the treatment. Rainfall during the first year totaled 17.8 inches.

Such low levels of contamination during the first posttreatment year are very encouraging, but a complete assessment of the contamination potential of karbutylate treatments requires further research.

Nutrient Changes

Nutrients released from decomposing chaparral litter are normally recycled into the living vegetation. When the plants are killed, however, the nutrients can be lost via leaching, runoff, and erosion. This phenomenon would be expected to continue until the area is revegetated and perhaps even afterwards, depending upon the replacement vegetation. Such loss of nutrients would deplete soil fertility and contribute to excessive enrichment of streams and lakes.

The maximum effect that a chemical conversion of chaparral on a granitic soil might be expected to have is being determined at Three Bar watershed F. Nearly all chaparral vegetation on this 68-acre watershed, including grasses and forbs, was either killed or topkilled by a broadcast soil application of karbutylate.

Composition of stream water changed surprisingly little following treatment. During the first posttreatment year, only nitrate ion was substantially increased in the stream water. The normal nitrate concentration in stream water from the untreated control watershed, about 0.2 p/m, was independent of precipitation and streamflow. In contrast, nitrate concentrations in stream water from the deadened watershed were highly dependent on precipitation and

streamflow. Nitrate increased to 24 p/m following a 2.1-inch rainstorm, and to 36 p/m following a 3.3-inch storm. Nitrate concentrations gradually declined to normal levels over a period of several weeks.

During the second posttreatment year, an intense 8-inch storm during the 1970 Labor Day weekend provided an opportunity to document what may possibly be the near-maximum effect of a single storm event on nutrient losses from a deadened chaparral watershed. It is remarkable that nitrate was the only ion affected by the heavy rainfall. It increased from a normal value of 0.2 p/m up to 56 p/m (a 280-fold increase), then gradually declined to 1 p/m in December. Nitrate increased to 20 p/m following a 3-day storm in December that yielded 2.2 inches of rain, then gradually declined, but did not return to normal until May. The nitrate concentration in stream water from the control watershed remained at a normal level of about 0.2 p/m throughout the year.

Properties of the stream water from the deadened watershed which were unaffected by the Labor Day storm were total soluble salts, electrical conductivity, pH, and the following ions: calcium, potassium, magnesium, sodium, chloride, sulfate, carbonate, ammonium, and phosphate. Bicarbonate concentration decreased slightly in the stream water from both control and deadened watersheds.

Although streamflow from the treated watershed has remained well above normal, nitrate concentrations have increased only after moderately heavy rainfalls. During prolonged dry periods, when the nitrate concentrations from the deadened and control watersheds were the same, loss of nitrate nitrogen from the deadened watershed was proportionately greater than that from the control watershed, however, due to the increased volume of streamflow.

We anticipate that nitrate will continue to be leached from the watershed in abnormal amounts until the organic nitrogen compounds are exhausted, or until vegetation is reestablished and a new steady state of nitrate loss is reached. Recent findings from older partial watershed conversions indicate that high levels of nitrate still persist 8 years after treatment, even though the areas were revegetated with grass and forbs.

Additional studies are needed on other soil types and with other types of watershed manipulations. Conversions need to be designed that will minimize nitrate enrichment of stream water. Studies on the effects of brush eradication on soil fertility, and determinations of nutrient budgets for natural and treated chaparral ecosystems are also needed for proper assessment of chaparral manipulations.

Effects of Brush Control on Wildlife and Livestock

Since most chaparral shrubs are not relished by domestic livestock, the carrying capacity of mature chaparral is relatively low. Annual carrying capacity ranges up to 10 animal units per section, depending on slope, accessibility, and vegetal composition. Stands with significant amounts of true mountainmahogany, desert ceanothus, hollyleaf buckthorn, and Wright silktassel may have somewhat higher stocking rates. Sprouts of shrub live oak, as well as the more palatable shrubs, provide fair forage after a fire. Forage value decreases as the shrubs mature. Shrubs also provide emergency forage during drought and occasional years of heavy snowfall (Pond et al. 1968).

Conversion invariably increases the forage production and carrying capacity for livestock. On the Tonto Springs beef study, Prescott National Forest, annual livestock weight gains averaged only 9.4 lb/acre/year on native chaparral, while animals grazing adjacent pastures converted to weeping lovegrass gained 81.4 lb/acre (USDA Forest Service 1969).

Both mule deer and white-tailed deer are common in chaparral areas. Populations vary locally from 4 or 5 to as many as 20 or 30 per mile^2 (Swank 1958), with an overall average in 1955 of perhaps 10/mile^2 (Hanson and McCulloch 1955). Populations tend to be high where shrub species composition is favorable, and low where shrub live oak and skunkbush form almost pure stands (Swank 1958). McCulloch (1973) found that mature chaparral was an important diet constituent for white-tailed deer on the Three Bar wildlife area. Mature browse represented up to 50 percent of the diet during late fall, winter, and early spring. In addition, the mast, fruits, and berries of mature browse constituted as much as 65 to 70 percent of the midsummer diet.

As with cattle, shrub sprouts provide better forage for deer than do mature or decadent shrubs. Therefore, providing suitable areas of sprout regrowth can have a beneficial effect on deer (Reynolds and Sampson 1943, Swank 1958, Reynolds 1967).

Studies conducted on the Three Bar watersheds by the Arizona Game and Fish Department (McCulloch 1972) showed that brush control on watershed C reduced two major white-tailed deer foods while it increased a third. All shrub fruits, important during summer, were eliminated and most palatable browse species such as hollyleaf buckthorn were killed. Herbaceous forbs increased greatly, particularly the summer-growing species, many of which bear some green basal foliage through winter. Although this food was probably the main reason for deer using watershed C more than the

adjacent untreated brush (Pase et al. 1967), forbs cannot totally substitute for the mast and browse removed by treatment, since deer never eat forbs exclusively, even in seasons of greatest forb abundance. Untreated cover must be retained nearby if the quality of deer habitat is to be maintained. Since no part of watershed C (95 acres) is more than 300 yards from a boundary, the deer using this watershed can easily reach and use adjacent untreated chaparral.

More specific data are needed as to the time of day and season of year during which deer use the treated watersheds. To this end white-tailed deer are being equipped with bells and radio collars and tracked by the Arizona Game and Fish Department.

Observations made on two belled white-tailed does in 1971-72 (McMichael 1972) indicate that during daylight hours the deer prefer undisturbed brush to treated chaparral for both feeding and bedding. These findings are at variance with the earlier observations based on pellet-group counts taken during the postfire period 1959 to 1968, which showed substantially more deer use on the treated sites. Either the deer use the treated areas much more at night (when observations were not made) than during the day, or some other explanation is necessary to account for the apparent discrepancy. More information of this type is needed to help clarify the ultimate value of the various herbicide-treated areas as deer habitat.

Deer-use patterns in chaparral near Prescott differ from those at Three Bar. Mule deer are dominant in this area. Chemical control on 38 acres of streamside shrubs and junipers at Whitespar watershed B has not affected deer use significantly. The data indicate, however, that deer use is concentrated on upper slopes and ridgetops. The next treatment phase will be imposed on these upper areas, and could affect deer more directly.

Rootplowing and seeding lovegrass at Tonto Springs near Prescott effectively converted chaparral to grassland. Deer use as indexed by pellet-group counts on 80-acre treatments was significantly and consistently lower on conversions by a ratio 1:3 (Urness 1974). However, forbs and grasses associated with the dominant lovegrass provided high-quality forage largely unavailable in mature chaparral stands.

Loe and White (1972) surveyed bird and small mammal populations on this and other rootplowed areas. Numbers of species were similar on treated and intact stands, but total numbers observed were higher on conversions.

In reviewing the significance of forage quality in wildlife management, Hanson and Smith (1970) suggest several reasons why habitat is improved by brush treatments. Opening up dense brush provides space for animal movement as well as an increase in the abundance and nutritive quality of new browse and forage. Also, the variety of food is increased as forbs become more abundant and shrubs sprout. The beneficial boundary or "edge" effect resulting from treatments is also known to improve wildlife habitats in general.

Large chaparral conversions can adversely affect wildlife. Repeated herbicide applications may tend to create monocultures, although fears of creating "biological deserts" are unwarranted. Conversion practices that intensively convert large areas to grass should be avoided (McCulloch 1972). Treatments should be small and irregular, with as many shrubs and forbs left within the treated areas as practicable to provide a variety of food. Probably no more than half the total areas should be converted (Reynolds 1972), but precise prescriptions have not been determined. The nonconverted areas need not be ignored. Periodic burning or some other form of treatment might materially improve them for wildlife.

SUMMARY AND CONCLUSIONS

Chaparral covers 3 to 4 million acres in Arizona. While land managers rate chaparral low in commercial value, it yields about 0.1 acre-ft of water per acre per year, and produces some forage and browse for game and livestock. It also provides food and cover for a variety of wildlife, and to many it is esthetically pleasing as a natural ground cover. Access is limited because of the dense brush, however, and protection against fire is difficult and costly. For many years the chaparral has remained under protective management only; no cultural practices have been applied to any significant degree to improve its natural productive capacity.

A continuing demand for agricultural water combined with a declining water yield from central Arizona watersheds during the 1940's and early 1950's provided the impetus for studies to increase the water supply from forest lands, including chaparral. Several experimental watersheds were established, the chaparral was treated, and effects of treatment on streamflow, erosion, wildlife, and grazing values were evaluated.

Streamflow has been substantially increased by eradicating deep-rooted shrubs and replacing them with shallow-rooted grasses and forbs that use less water. The amount of increase varies considerably between sites because of complex interactions between precipitation, soil, aspect, local climate, and other factors that

affect the disposition of water by the indigenous shrub cover. The method and amount of shrub reduction also affect treatment response.

Posttreatment increases in average annual streamflow on the experimental watersheds varied from one-third inch to over 5 inches. Estimates can be made of onsite increases in water yield if conversion to grass reduces shrub cover to less than 10 percent. For example, if mean precipitation is 22 inches the expected onsite increase from figure 19 is 3.8 inches. These gains in water yield can be maintained if posttreatment use and maintenance of the grass cover are well planned, and geared to changing conditions and needs.

The tendency for large increases in wet years and for flows to be prolonged into or through dry periods have profound effects on aquatic habitat and channel environment of the normally intermittent headwater streams. Some adjustments in the channel are likely under prolonged, high flows; channel erosion may accelerate until the system conforms to the new level of activity. On the other hand, stability is added when water-loving plants such as sedges, watercress, willows, and alders invade where chaparral species once grew. Wildlife, livestock, and water-oriented recreation activities will benefit from these changes. Overall, enhancement of the stream environment is expected.

Some of the extra water will be lost to riparian vegetation along streams draining the converted areas, particularly during dry periods when streams normally do not flow. However, since nearly 80 percent of the increase is produced in the dormant season when streams are normally active, the proportion lost should be small, probably less than 20 percent.

Chaparral control methods that have proved effective in Arizona are mechanical, prescribed burning, chemicals, and chemicals in combination with the others. Rootplowing is the only mechanical method used extensively in chaparral conversion. Steep slopes and rocky soil are the limiting factors; less than 8 percent of the chaparral can be treated this way. Where it can be used, however, the rootplow offers the best method of shrub control. Shrub mortality is usually 80 percent or better, and re-treatment is seldom necessary. Grass is readily seeded in the plowed soil, usually in the same operation. Costs are moderate.

Prescribed burning modifies the density, stature, and composition of brush stands, but kills outright only a few species such as manzanita. Most shrubs sprout vigorously after fire to the detriment of grass and water savings. Therefore, if eradication is a management objective, burning must be combined with other control methods. Two uses of prescribed fire offer promise and should be researched further. Fire can be used to topkill and open up mature stands, and to prepare a seedbed for grasses. Maintaining grass after resprouting brush or brush seedlings start to gain competitive advantage over the young grass stand may be difficult. Here chemicals can be used to good advantage to maintain the balance in favor of grass until grass is established well enough to carry fire. At this stage, fire can be used repeatedly to topkill and thus control shrubs.

Herbicides, properly used, can perform an important function in eradication and control of woody plants. A variety of chemicals have been used; several are being tested for effectiveness and for contamination of soil and stream water. Chemicals may be applied to the foliage as sprays or to the soil surface in the form of granules or pellets. Of the foliage sprays, the phenoxy group (2,4-D; 2,4,5-T; silvex) and picloram, as well as phenoxy-picloram mixtures, are commonly used. The phenoxy herbicides are most economical for large-scale projects, but they do not provide adequate control of the dominant shrubs. Substantial shrub mortality cannot be expected until after several annual applications. One advantage, however, is that they are more toxic to brush than to grasses, thus favoring grass in conversion practices.

Soil treatments offer several advantages over foliar sprays for controlling brush. Application is easier and the problem of drift is eliminated. Selective treatment of individual shrubs or species is easy by hand application, although this method is not economical for large-scale treatments. Soil-applied chemicals are for the most part potent brush killers (eradication of most shrubs is possible with one application) but most are toxic to grass and other desirable plants as well. Selectivity is possible by hand application but not by broadcasting, although broadcasting large pellets 3 to 6 ft apart may kill shrubs yet allow grasses to grow between. This technique is being explored.

Herbicides which are effective as soil treatments are fenuron, picloram, karbutylate, and bromacil. None is registered for watershed use as yet, and the availability of fenuron is uncertain. Cost of these chemicals at application rates high enough to assure shrub eradication in one or two treatments may be prohibitive, although expensive treatments may be economically feasible if they need not be repeated for many years.

The herbicides discussed in this report were tested experimentally, and their use does not imply that they are recommended or registered for watershed use. The use of any herbicide for project or commercial purposes must conform with regulations of the Environmental Protection Agency and be registered for the intended use. Regulations will undoubtedly become in-

creasingly strict in order to insure adequate protection of the environment. Only when a product passes the many toxicological hurdles required is it granted registration for use as specified on the label. It is important, therefore, that label directions be read carefully and strictly followed. Latest registration information regarding herbicides can be obtained from the Agricultural Extension Service of the U.S. Department of Agriculture.

Stream water from the treated watersheds shows moderate to low contamination by chemicals applied. Only in large-scale treatments would herbicide contamination be of concern; even then, dilution with water from untreated areas would probably reduce chemical concentrations to harmless levels. Water quality can also be endangered by accelerated leaching of nutrients from treated areas when the normal nutrient cycle is interrupted by killing the vegetation. Limited studies indicate that nitrate concentration is the only water property materially affected by complete deadening of brush and herbaceous vegetation on a granitic watershed. More study is needed to determine the extent of loss, and how it affects soil fertility and enrichment of streams and lakes.

Erosion probably will increase for a time following most conversion practices. The impact is likely to be greatest from broadcast burning, and least from mechanical and chemical control of shrubs, if replacement cover is established soon after treatment. Treatment on excessively steep slopes (over 60 percent) or particularly unstable soils should be avoided. Safe conversion on slopes between 40 and 60 percent depends largely on soil and site factors which vary considerably within the chaparral. Treatment criteria should be developed on the basis of soil, anticipated use, and maintenance problems peculiar to each site. Over the long run, conversion should reduce erosion by reducing or eliminating the heavy erosion cycle set off by periodic wildfires. This reduction is based on the assumption that the replacement cover will protect the soil as well or better than brush, and that grazing and other land-use activities will be carefully planned and followed.

Conversion increases forage for livestock, and influences wildlife in several ways. On converted areas, near complete eradication of shrubs (necessary if water yield is the major objective) will eliminate the habitat of some species while providing new habitat for others. If treatment areas are kept small and interspersed with native chaparral, protective cover and browse will always be available nearby, and the edge effect created by the treated openings will enhance the overall wildlife environment.

Although much remains to be learned about chaparral in Arizona, enough information has been gained to clearly indicate that the productive capacity of these areas can be greatly enhanced. Increased water, forage, wildlife, and recreation benefits can be realized either singly or in combination by modifying the shrub cover. Results from research and pilot testing suggest that it will be possible to design chaparral conversions that will be safe, effective, and not detrimental to the environment.

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1974. Chaparral conversion potential in Arizona. Part I: Water yield response and effects on other resources. USDA For. Serv. Res. Pap. RM-126, 36p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

On areas favorable for treatment, conversion to grass reduces fire hazard and substantially increases water yield and forage for livestock. If treatment areas are kept small and interspersed with native chaparral, protective cover and browse for game animals will always be available nearby, and the edge effect created by the openings will enhance the overall environment for wildlife. Chaparral control methods that have proved effective in Arizona are rootplowing, prescribed burning, chemicals, and chemicals in combination with the others. Stream water from treated watersheds shows moderate to low contamination by herbicides. Over the long run, conversion should reduce erosion by reducing or eliminating the heavy erosion cycle set off by periodic wildfires in unmanaged chaparral.

Keywords: Watershed management, chaparral, brush control, water yield improvement, soil erosion, sediment yield, habitat improvement.

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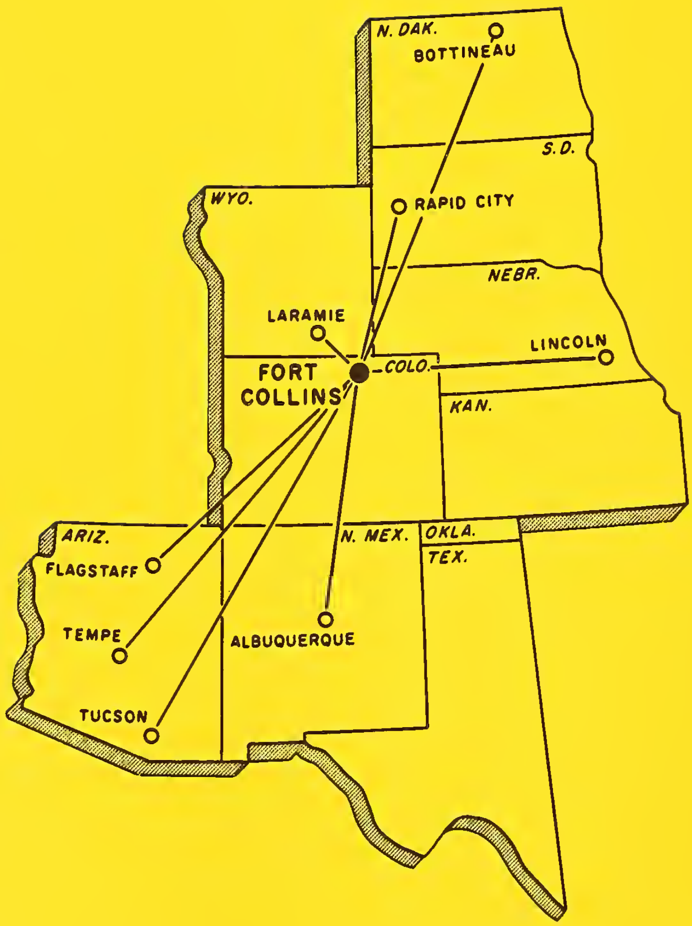

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